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PHOTOGRAPHIC SCIENCE AND ENGINEERING
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The Mechanism of Photographic Development

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The reduction of silver ions in ordinary development proceeds by at least two paths — a direct reduction at the silver–silver halide interface, and a solution-physical development process in which the silver ions first pass into solution and are subsequently reduced at a silver surface. The mechanisms of direct interface development and of physical development are discussed from the viewpoint of adsorption-catalysis. The electronic properties of the catalyst are important to its action in accelerating the reduction of silver ions by the developer. Under most practical conditions, the rate of solution-physical development is determined by the rate of solution of the silver halide rather than by the rate of the catalyzed reduction of silver ions. The kinetics of development of the individual grains in an exposed emulsion are discussed in terms of the various reactions which can occur.

The purpose of this paper is to present some views on the mechanism of photographic development which appear to be in good agreement with experimental data. The mechanisms suggested are not essentially new, but draw heavily on previous statements of electrochemical and catalytic mechanisms.[1] The discussion will be confined primarily to the mechanisms of reduction of the silver ions in the initial and subsequent stages of development. Filament formation in the developed silver appears to be determined by factors which affect the crystallization of the reduced silver, and this subject will not be discussed here.

Direct (Chemical) and Solution-Physical Development

Development of the silver halide grains in an exposed emulsion can proceed simultaneously by at least two distinct paths. In the first, silver ions at the solid interface between the silver halide and the latent-image nuclei or developing silver centers are reduced to silver by the action of the developer. Development which proceeds in this way has been called "chemical" or "direct" development. In the second, silver ions from solution diffuse to silver centers, such as those supplied by the latent image or by development of the first type, and are then reduced to silver by the action of the developer at the silver surface. This mechanism has been called "physical" development, for purely historical reasons. In ordinary development, where no soluble silver salt has been added to the developer during its preparation, the silver ions involved in physical development come from solution of either the exposed grains themselves or from nearby grains. Accordingly, this type will be referred to as "solution-physical development."

The relative extent to which direct and solution-physical development participate in ordinary development depends upon the photographic material used and the makeup of the developer. As an example of the effect of the material, Kodak Developer D-76 develops a fine-grain, pure silver chloride emulsion almost entirely by the solution-physical mechanism, whereas direct development plays a more important part than solution-physical development in the action of the same solution on exposed bromoiodide emulsions of similar grain size. Examples of the effect of the composition of the developer have been given in a previous publication[2] and other examples will be given in this paper.

Mechanism of Physical Development

The kinetics of physical development have been studied extensively with the aid of model systems.[3–6] These studies have been reviewed elsewhere[7,8] and only some of the results will be cited here.

Experiments with hydroquinone, catechol, hydroxylamine, and *p*-phenylenediamine[7] show that the rate of physical development of colloidal silver nuclei (suspended in gelatin or gum arabic solution) by a solution which contains a soluble silver salt and the developing agent can be represented by the equation:

$$dM/dt = k\,[Ag^+]^{\alpha}\,[D]^{\beta} \cdot S \cdot e^{-E/RT},$$

where M is the mass of developed silver, D represents the developing agent, α and β are fractions or equal to one, depending on the developing agent, S is the surface area of the developed silver, E is the activation energy, R is the gas constant, and T is the absolute temperature. The value of α for hydroquinone, catechol, and hydroxylamine development is a fraction, usually 0.5 to 0.7. This dependence on a frac-

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tional power of concentration is readily explained if the silver ions are rapidly adsorbed by the silver surface and a pseudo-equilibrium adsorption is established. There is evidence from direct adsorption studies to support this assumption.[7] A silver ion adsorbed by a silver surface may, in effect, become a part of that surface and of the system of silver ions plus mobile electrons which makes up the metal. The system as a whole would then be deficient in electrons because of the adsorbed silver ions, and would be positively charged. The developer could supply the electrons to make up this deficiency. The rate-determining step could be the transfer of electrons from the developer to the silver metal, as suggested by Bagdasar'yan.[9]

The over-all activation energy calculated[3] for the reaction of hydroquinone with silver ions in the presence of a silver surface at pH 5.8 is 12.7 kcal/mole. When allowance is made for the heat of dissociation of the hydroquinone, the corrected activation energy is approximately 8 kcal/mole. Accordingly, relatively few of the hydroquinone ions which contact the silver surface transfer electrons to that surface or to the silver ions on it.

The value of β for development by hydroquinone and catechol is one. There is no evidence for adsorption of either of these agents by silver. The value of β for hydroxylamine and for *p*-phenylenediamine is less than one, and this fractional-power dependence could be explained on the basis of adsorption of these particular developing agents by the silver prior to the electron transfer. The value of α for *p*-phenylenediamine, unlike that for the other developing agents, is one. The silver surface may acquire from adsorbed *p*-phenylenediamine excess electrons which are subsequently neutralized by silver ions contacting the silver surface from solution, or the silver ions may react directly with the adsorbed developer.

Faerman and Voeikova[5] studied the effect of various colloidal nuclei on the rate of reduction of silver ions by hydroquinone, *p*-aminophenol, and *p*-phenylenediamine. Silver is an effective catalyst for all three developing agents, and selenium and various metal sulfides also are catalysts. Lead sulfide is effective in catalyzing the reaction of hydroquinone and *p*-aminophenol, but is only a weak catalyst for *p*-phenylenediamine. Vanadium pentoxide catalyzes the reaction of hydroquinone and *p*-aminophenol, but not of *p*-phenylenediamine. These differences in the behavior of lead sulfide and vanadium pentoxide towards the three developing agents could be explained by differences in the adsorption characteristics, since adsorption of the *p*-phenylenediamine by the catalyst is important to its reaction, whereas adsorption of silver ion is important to the hydroquinone reaction. The results are not readily explained if the catalyst acts merely as a conductor for electrons and adsorption effects are not important. Faerman and Voeikova found that silver halides do not act as catalysts. This is not surprising, since the adsorption of silver ions and developing agent by the silver halides is of an entirely different character from the adsorption by silver.

Mechanism of Direct (Chemical) Development

The same general explanation might be given for chemical development as that just outlined for physical development. Silver ions at the silver–silver halide interface, particularly those ions which occupy kink sites, may become detached from the silver halide lattice and incorporated into the silver metal. Various model experiments[10–12] have shown that development is possible by a system in which a metal acts essentially as an electron-conducting bridge between the silver halide and the developer. However, most silver ions from a silver halide lattice will not be transferred as readily to the silver nucleus as silver ions from solution. The transfer will be facilitated if the silver nucleus acquires a high enough electric charge from the developer. This may indeed be the case in development under conditions where a silver electrode becomes strongly electronegative on contact with the developer solution, and the energy of activation for the electron transfer is very low. However, this simple mechanism is less attractive for development under most practical conditions, since it does not offer a ready explanation for important aspects of the kinetics.

In development by most agents, adsorption of the developing agent *by the silver halide* or at the silver–silver halide interface appears to be of major importance in determining the rate of development. Evidence for the importance of this type of adsorption has been reviewed previously.[13–15] As a striking example of the effect of adsorption, it has been shown previously[14,16] that monolayer adsorption of a strongly held dye, such as 3,3′-diethyl-9-methylthiacarbocyanine or 1,1′-diethyl-2,2′-cyanine ion, will greatly decrease or even prevent chemical development by hydroxylamine, although the same dyes are substantially without effect upon physical development by hydroxylamine and hydrazine, and actually accelerate chemical development by hydroquinone. The dyes prevent adsorption of the hydroxylamine by silver halide, but promote adsorption of the hydroquinone.

Adsorption of the developing agent by the silver halide probably involves complex or salt formation between the silver ion and the developing agent. Amine developers can form complexes with silver ions through the amino groups; the hydroxyl developers can form salts between the silver ion and an ionized hydroxyl group. In either type of adsorption, silver ions are moved from their normal positions in the silver halide lattice. Some halide ions may pass into solution at this stage. For example, adsorption of *m*-aminophenol by silver bromide in slightly alkaline solution is accompanied by liberation of bromide ions into the solution, although no reduction of silver bromide by this agent occurs (unpublished experiments). Very probably, absorption of the developing agent, *p*-aminophenol, likewise causes bromide ions to pass into solution before any reduction of silver ions occurs. Once the adsorption complex or salt is formed, it has only to undergo electronic rearrangement to break up into a silver atom and oxidized developer.

If the complex or salt forms between a good developing agent and silver ion in solution, or on a pure silver halide surface (absence of chemical ripening centers), the activation energy of the electronic rearrangement is relatively high. Thus, the activation energy of fog formation by a good developing agent acting on an emulsion which has not been deliberately chemically sensitized is higher by several kilocalories per mole than the activation energy of latent-image development in an emulsion area which has received a moderately high exposure to light, or in an emulsion which has been chemically oversensitized. The rate-controlling step in fog formation in the unsensitized emulsion appears to be the "uncatalyzed" reaction between the silver ions and the developing agent.[17] As soon as a suitable silver nucleus is formed by this reaction, the more rapid catalyzed reaction takes over.

If the activation energy of the uncatalyzed electronic rearrangement in the complex is very low, or if the activation energy for direct transfer of an electron to either a silver ion in solution or in the pure silver halide crystal is very low, the reducing agent should have little or no power of selective development. The failure of stannite ion to act as a developer may be associated with the low energy of activation of the reaction between this ion and silver ion in the absence of silver nuclei.[18] However, it may be noted that stannite ion can act as a physical developer under proper conditions. The reaction between stannite and the silver sulfite complex usually employed in physical development is very rapid and there is no evidence of silver catalysis. Even when the silver ions are more tightly bound in the silver thiosulfate complex, reaction occurs without catalysis and the stannite ion reduces the complex directly. However, if a silver salt is dissolved in a strong solution of potassium iodide (0.55 *M*), the reaction between the silver iodide complex ion and stannite is markedly catalyzed by silver nuclei.[3] The activation energy of the uncatalyzed reaction is relatively high compared with that of the silver-catalyzed reaction.

Stannous ion itself reacts with silver bromide much more slowly than does vanadous ion and does not act as a developer. The relatively slow reaction of the stannous ion may depend upon the fact that it must lose two electrons to pass into its next higher oxidation state. If this oxidation cannot proceed stepwise, the stannous ion must react simultaneously with two positively charged silver ions, a relatively rare event. The presence of a "silver electrode" in the form of latent image or partially developed silver does not facilitate the electron transfer.

If the reducing agent forms a relatively stable soluble complex with silver ions and causes the silver halide to pass into solution readily, direct development may not occur. The silver halide may be "fixed out" before significant development can occur. Thus, sulfite ion does not act as a direct developer, although it will act as a fairly poor physical developer at sufficiently high temperatures.

Adsorption of the developing agent–silver-ion complex by a material of suitable electronic properties, such as a silver surface, promotes the electron transfer. Suitable adsorption of the complex at the silver–silver halide interface may occur much more readily than simple adsorption of silver ions from the halide lattice. This adsorption of the complex lowers the activation energy necessary for the electron transfer. Even so, the activation energy in some instances is rather high. For example, the activation energy for image development by some of the *p*-phenylenediamine derivatives[19] is more than 20 kcal/mole, although the activation energy for hydroquinone[20] under the same conditions is only 5–8 kcal/mole for silver bromide grains which have received a moderately high level of exposure.

An important distinction between chemical development and physical development by hydroquinone is that the rate of the former process shows but little dependence[21] on the surface area of the silver (as distinct from the area of the silver–silver halide interface), whereas the rate for physical development is proportional to the surface. Apparently, hydroquinone molecules or ions which contact the silver surface at a distance from the interface contribute relatively little to the chemical development process. The interface moves as development proceeds throughout the grain, so that adsorption complex formed on pure silver halide surface eventually becomes situated at the interface. Migration of adsorbed developer along the silver halide surface also may play a part in maintaining a supply of developing agent at the interface, and, too, migration of silver ions along the surface may be a factor.

Although it has commonly been recognized that solution-physical development can occur to some extent under normal conditions of development, it is only recently that even a semiquantitative method[2,22] has been available for determining the relative amount of solution-physical development occurring under a particular set of conditions. Developing agents such as *p*-methylaminophenol, hydroquinone, and catechol have negligible solvent action on silver halides in themselves, and the solvent action of the developer solution is determined primarily by the other components in that solution. Under most practical developing conditions, the specific rate of reaction of silver ions from solution with the developer at a silver surface is high. Provided sufficient silver surface is available, the rate of solution-physical development is determined not by the rate of this reaction but rather by the rate of solution of the silver halide. The rate of solution-physical development, accordingly, is increased or decreased by the addition of an agent which increases or decreases the rate of solution. The rate of solution of silver bromide in a potassium bromide solution or a sodium sulfite solution is dependent only to a minor extent on the pH of the solution on the alkaline side. The rate of direct development on the other hand, is markedly dependent on pH for many organic developers, and

increases with increase in pH. Accordingly, the relative importance of solution-physical development decreases with increasing pH of such a developer if the composition of the solution is otherwise held constant.

Some developing agents are themselves solvents for silver halide, and solution-physical development generally plays a more important role in the solutions which contain such agents. *p*-Phenylenediamine exerts a marked solvent action for silver bromide, particularly when the agent is present at high concentrations. Some *p*-phenylenediamine developers apparently act almost wholly by solution-physical development. The relative importance of this type of development, however, can be altered over a rather wide range by changing the conditions of development. This agent is a particularly interesting one for use in a study of the role of solution-physical development in determining the general characteristics of the developed image. Under some conditions, the rate of solution-physical development by this comparatively weak developing agent is determined in part by the rate of reduction of the silver ions at the silver surface, as well as by the rate of solution of the silver halide.

Conventional developers contain sodium sulfite as a preservative against aerial oxidation and the accumulation of oxidation products. Sulfite also has a well-known solvent action for silver halide, and this solvent action can modify the course of development and fog formation in several ways. Sulfite in amounts commonly used in developers (30 – 100 g per liter) increases the equilibrium solubility of silver bromide by several orders of magnitude. This solvent action can be of importance in promoting the development of internal or semi-internal image and fog by dissolving away protecting silver halide. However, the effect of the sulfite on the rate of solution of the silver halide is more important than its effect on equilibrium solubility in determining the relative extent of solution-physical development, and sulfite increases the rate of solution by only a few-fold at the sulfite concentrations commonly employed. This is quite enough to have significant photographic effects under proper conditions, and certain low pH developers, such as Kodak Developers D-23 and D-25, apparently owe their fine-grain properties to the relatively large extent to which solution-physical development occurs with these solutions.[2] The rate of solution is essentially independent of pH for these and higher pH values, and this is the rate which determines the rate of solution-physical development by the *p*-methylaminophenol developers. Hence, an increase in pH causes a decrease in the relative importance of solution-physical development and a loss in fine-grain properties. Solution-physical development may not be important, however, until direct development has supplied a sufficient amount of silver surface.

The mechanism of chemical development outlined in the preceding pages, which is essentially a restatement of the adsorption-catalysis mechanism, is not in basic conflict with the electrochemical concept of development. The electronic properties of the metal are undoubtedly of importance in promoting the electron rearrangement which results in the formation of silver atoms and oxidized developer. Mere adsorption is seldom a basis for heterogeneous catalysis. The nature of the adsorption is generally of primary importance, and this depends on the properties of the solid adsorbent. The adsorption-catalysis picture, while losing none of the basic features of the electrochemical concept, gives a straightforward explanation of the kinetics of development.

Development of Individual Grains

The photographic sensitive layer contains a large number of individual silver halide grains. The usual density and silver measurements made on the developed material give integral values, and the grains are treated as an ensemble. However, the grain in many ways acts as a unit, and the time required to develop the various individual grains may vary widely for a particular material. Development of the individual grain generally starts at one or a number of relatively small areas on the grain surface, and reaction proceeds from those areas. Development of an individual grain can start by either or both of the paths previously discussed (direct and solution-physical development), and the relative extent to which each mechanism participates in the subsequent reduction of the grain can change as development proceeds.

A considerable time may elapse before any evidence of a start of development of a particular grain can be detected. This time will be referred to as the "individual induction period," to distinguish it from the induction period usually defined in terms of the density–time of development curve for the grain ensemble. Under some conditions, a large portion of the grains of the ensemble develop in a roughly parallel fashion. The induction periods of the individual grains are roughly equal, and density increases primarily because of an increase in the size of the developing silver specks as development proceeds. This condition often is obtained when a simple silver bromide or bromoiodide emulsion is given a moderate- or low-intensity exposure corresponding to the shoulder of the characteristic curve and developed in a simple developer.[23,24] Under other conditions, a marked variation can occur in the induction periods of the individual grains, and the density at any stage of development is determined, in the main, by the number of grains which have developed substantially to completion. As development progresses, grains with longer and longer induction periods develop. This situation has been observed at low exposure levels corresponding to the toe of the characteristic curve. For conditions intermediate between these two extremes, some grains with relatively short induction periods will start to develop quickly and the duration of development of the individual grain will be considerably longer than the induction period. Other grains will have induction periods which are as long

as, or longer than, the duration of development of those grains beyond the induction period.

The induction period of development of the individual grains is determined by the properties of the latent image, the conditions of development, and the nature of the developing agent. The dependence of the induction period on the charge of the developer ion and on the surface charge of the silver halide grain has been discussed in several publications,[15, 23–28] and will not be dealt with further here. Individual grain induction periods exist quite apart from the charge effect, although the latter may have a marked influence upon the magnitude of the induction period.

Temperature coefficient studies[23, 29] have indicated that the activation energy of development by a particular developer varies with the exposure, and may vary among the individual grains in an area which has received a moderate or low exposure. This is primarily an induction-period effect, since there is no evidence that the rate of development of a particular center beyond the induction-period stage depends significantly on the exposure.

For any particular set of development conditions, size and possibly configuration of latent-image nuclei may determine the duration of the induction period. It has been shown[31–33] that latent image produced by low-intensity exposure starts to develop faster than that produced by a high-intensity exposure which will give the same ultimate developed density. An extensive investigation of the dependence of the development characteristics upon the intensity of the exposure and the degree of chemical sensitizing has been reported by Eggert and Okamoto.[33] There are experimental and theoretical reasons for believing that low-intensity exposure produces larger and fewer latent-image nuclei on the average than high-intensity exposure.

If the silver nucleus in contact with the developer must be at, or above, a certain critical size before rapid development sets in, a grain which contains only nuclei of smaller size will reach the rapid development stage only after at least one nucleus reaches the critical size. If the nucleus is largely buried in the silver halide, the induction period could represent the time required for solvent action to excavate it (but not isolate it from the silver halide). The developer also may slowly displace some development-restraining adsorbed material.

Otherwise, there are several ways in which the critical size could be reached by the action of the developer. The same reaction or reactions may occur during the induction-period stage as during the rapid process beyond the induction period. Reaction in the induction-period region may simply occur at a lower rate because a higher activation energy is required for the reaction at such small nuclei. The energy conditions for a nucleus which contains only a very few silver atoms may well be different from those for a larger silver particle. A type of "latensification" reaction also may occur by a catalytic breakdown of previously unreacted chemical sensitizer, as suggested by Sutherns and Loening.[34] Finally, an uncatalyzed reduction of silver ions by the developing agent may play a part. This reaction could help increase the size of the nuclei in the following way:

Any agent which will develop a silver halide grain at a moderate rate will also react with silver ions in the absence of latent-image nuclei. The reaction can take place between developer and silver ions in solution, or between developer adsorbed by the silver halide and silver ions which are a part of that surface. The uncatalyzed reaction of developing agents with silver halide on the surface of the latter may occur preferentially at centers where there is a high local density of kink sites which, according to Mitchell's views, are the centers where latent-image formation occurs. Such a reaction in the absence of nuclei formed by exposure would lead to fog formation when a nucleus of sufficient size was produced. Similarly, reduction of silver ions in solution could eventually lead to the formation of catalytic nuclei which would promote solution-physical development fog. If an exposure-formed nucleus of less than the critical size existed before the immersion of the emulsion in the developer, silver formed by reaction of the developer in the manner just described may act to augment the exposure-formed nucleus and bring it to the critical size. If this occurs, the "fogging" action of the developer would also act to some extent as a latensification.

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A Sensitometric Study of Film and Rapid Processing Solution Combinations

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Sensitometric studies of a variety of black-and-white emulsions processed in developers and monobaths showed that rapid developers produce acceptable results in most instances, although fog, speed, and gamma varied significantly, depending on emulsion type, composition of developer, and processing time. In general, monobaths performed differently, their action depending primarily on the emulsion characteristics, although with compatible combinations good results were obtained in less than or the same time required by the two-step process. Qualitative data are given on processing uniformity, film handling characteristics, and solutions used.

Monobaths have been recommended and used for the rapid processing of photographic materials because, in comparison with conventional two-step processes, they offer such advantages as simplified processing equipment, savings in space and time, and freedom from a rigid processing schedule.[1] These advantages, however, are usually offset by several shortcomings, of which a loss in emulsion speed and contrast, high fog, and instability of solutions are most notable. Considerable and successful efforts have been made to overcome these limitations of monobath solutions,[1,2,3,4] but in most instances the new solutions have been custom formulated for specific films and processing conditions. It was of interest, therefore, to evaluate the effectiveness of the monobaths that have been recommended when used with a variety of films and to compare their performance with that of rapid developers that are employed in the more common two-step process of separate development and fixation. Such an investigation has been carried out by means of standard sensitometric methods at a normal processing temperature of 68 F.

Materials and Formulas

The films and solutions that were tested are listed in Table I. Each film was processed in all the solutions for varying periods of time. Formulas for the Boston University (BU) monobaths have been released[1,2,3] (Table II) but Maurer monobath formulas have not been published, although two patents pertaining to them have been granted.[5] Undiluted rapid and general purpose developers were prepared from packaged chemicals, as was the Kodak Rapid Liquid Fixer used in the two-step process.

Test Procedure

Films were exposed on an Eastman Intensity Scale sensitometer, Special Type 1B. (Proper exposure time for each film type for normal processing in Kodak Developer D-19 was determined by trial.) This instrument was not calibrated in the infrared region and

TABLE I
Emulsions and Rapid Processing Solutions Tested

Films	Solutions
Kodak Aero Super-XX, Class L, Type 1B	Maurer Monobath 60C4
Kodak Aero Super-XX (SO-1121).	Maurer Monobath 60C4M (modified)
Kodak Infrared Aerographic, Class K, Type 1A	Maurer Monobath 66B2
Kodak Aero Tri-X, Class N, Type 1B	Maurer Monobath 66E3
Kodak Miniature Tri-X	Maurer Monobath 62A2
Kodak Contrast Pan	BU Monobath 348 (Refs. 2 and 3)
Kodak Plus-X	BU Monobath 315 (Refs. 2 and 3)
Kodak Panatomic-X (35 mm)	BU Monobath 403 (Refs. 2 and 3)
Kodak Micro-File	Southwest Products Inc., Swiftol
Ilford HP-3	Kodak Dektol
Ilford FP-3.	Kodak D-19
Ilford Pan-F	Plymouth Products Co., Inc., Ethol 90
Ansco Telerecord	
Kodak Aero Super-XX (SO-1166)*	Ilford Contrast FF

* Now designated by Eastman Kodak Co. as Plus-X Aerecon.

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* Formerly Boston University Physical Research Laboratories.

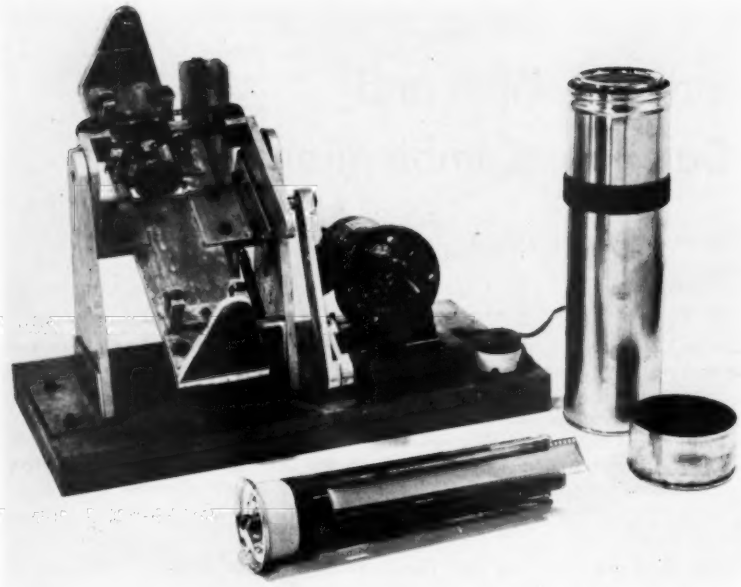


Fig. 1. Film processor for 35mm sensitometric strips.

therefore speed values of Infrared Aerographic film could not be determined.

A Dewar flask was used for processing. It was fitted with a rubber "Snap-Tite" stopper and a Plexiglas rack that holds four 10-inch 35mm film strips (Fig. 1). The flask is encased in a stainless-steel jacket which has a light-tight cap. After the flask was filled with solution, loaded, and capped, it was placed in a motor-driven unit which rotated it about its longitudinal and traverse axes.

Films were processed at 68 F for at least three different time periods ranging from 7 seconds to 11 minutes. Two-step processing times include fixing, normally for 1 minute, although Kodak Super-XX SO-1121 and Kodak Aero Tri-X films required $1^1/_2$ minutes fixation. At the end of the indicated times, the strips were immediately placed in running water.

TABLE II
Formulas for BU Monobaths

Constituent	315	348	403
Water (110 F)	750 ml	750 ml	750 ml
Lactose	—	—	50 g
Metol	10 g	33.5 g	10 g
Sodium sulfite (des.)	50 g	40 g	50 g
Hydroquinone	40 g	15 g	50 g
Potassium alum	20 g	20 g	20 g
Sodium hydroxide	35 g	30 g	35 g
Sodium thiosulfate	110 g	50 g	110 g
Anti-Fog #2 (0.5% soln.)	20 ml	20 ml	20 ml
Triamol (immed. prior to use)	—	—	7.5 g
Water to make	1000 ml	1000 ml	1000 ml

They were dried under normal room conditions.

ASA diffuse densities were measured on an Ansco-Macbeth Densitometer and the average values of four strips used to plot characteristic curves. D-19 developer was used as a control on all emulsions.

Criteria

Film speeds are expressed in terms of half-gamma values. This method is used at the Boston University Physical Research Laboratories and at the Wright Air Development Center. The half-gamma speed is derived from that point on the toe of the characteristic curve at which the gradient of the curve is one-half gamma and equals one-half the reciprocal of exposure in meter-candle-seconds at that point.

When the straight-line portion of a characteristic curve was insufficient to permit standard derivation of gamma, the average gradient of the curve above the toe portion was determined. The fog values that are given here include base density and density contributed by residual silver halides in instances where clearing was not completed in the allotted processing time. Consequently, fog values decreased in some monobaths test series as processing time was increased.

Results

Speed, fog, and time-gamma data for all film and processing solution combinations tested are given in Figs. 2-15.

Monobaths were mixed from reagent-grade chemicals with little difficulty. Several of the solutions gave off ammonia fumes and some had to be prepared with extra care to prevent premature aerial

oxidation. On standing, some of the monobaths deteriorated rapidly. They varied in hue from yellow (315 and 348) to tan (66A2, 66B2, and 66E3) to deep blue-black (60C4, 403, and 60C4M). All of the monobaths caused noticeable softening of emulsions, but especially hardened films were not seriously affected. The formation of silver sludge on processing equipment and occasionally on the films themselves, was another disadvantage of the monobaths.

The more conventional, high-energy developers were easy to mix and use. However, they usually produced mottled images with thin emulsions at short development times.

Processing Time

A minimum useful processing time for each combination, based on data obtained in this study, is given in Table III. In evaluating performance of the combinations studied, the following arbitrary standards were adopted:

1. Fog level below 0.5
2. Gamma above 0.5
3. No image reversal
4. Negligible mottling and staining
5. Emulsion fully cleared (fixed)

For "borderline" results, a minimum time has been given, along with an indication of undesirable effects. Processing times longer than those indicated usually produced better results.

Discussion

The data resulting from this study may be used as a basis for the selection of a particular combination of emulsion and processing solution to perform a specific task. There appears to be no universal rapid process-

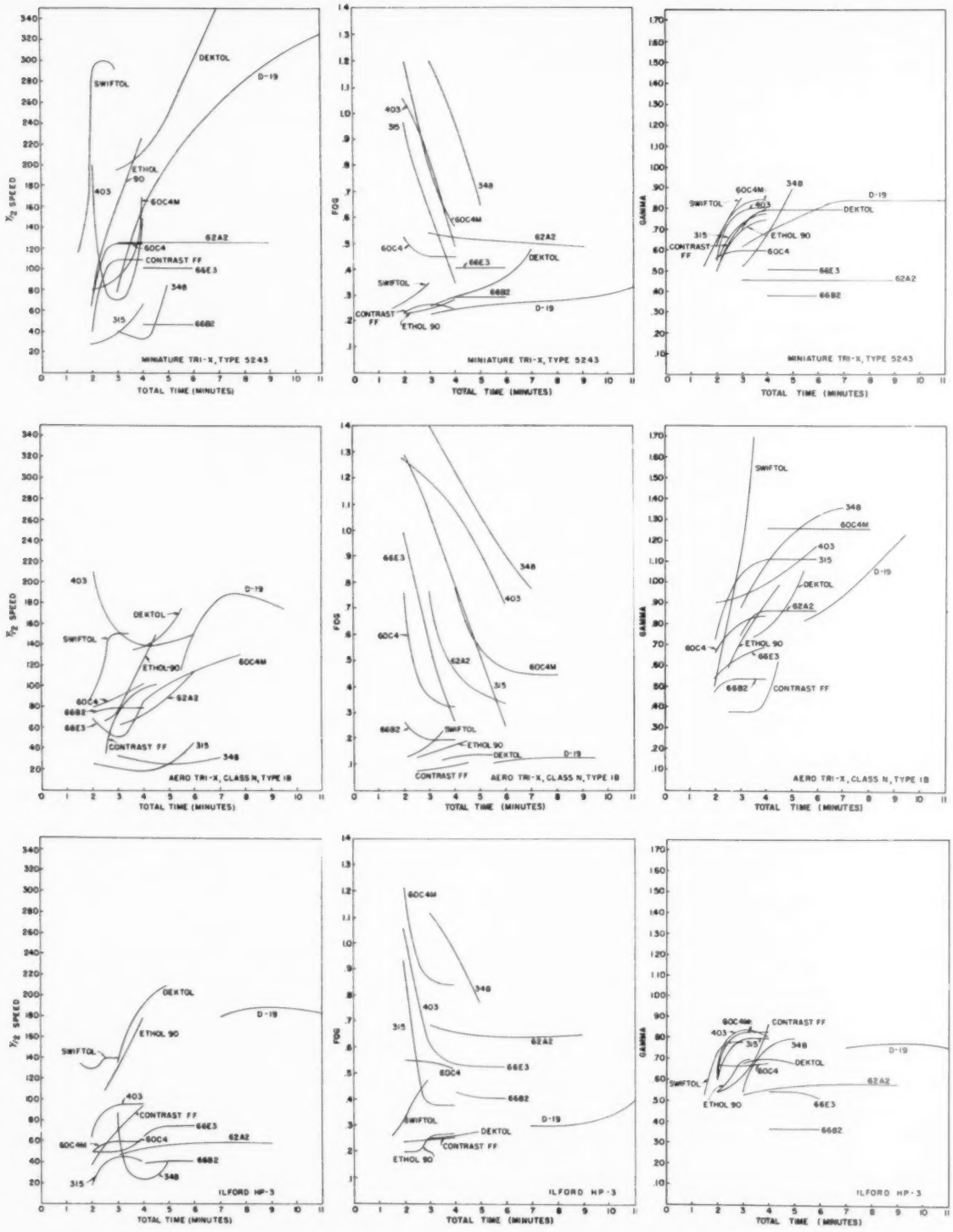
TABLE III
Minimum Processing Time in Minutes*

Emulsion	Solution												
	60C4	60C4M	62A2	66B2	66E3	315	348	403	D-19	Dektol	Ethol 90	Contrast FF	Swiftol
Aero Tri-X	3	6	6	3	4	6	NR R, F	NR F	7½	5½	4½	4	3
Miniature Tri-X	3	NR F	NR G	NR G	4	4	NR F	NR F	5	5	4	3	2½
HP-3	NR F	NR F	NR F	NR G	4	3	NR F	NR F	9	4	4	4	2
Aero Super-XX	2	3	NR G	4	2	3	5	3	9	4	4	4	2
Aero Super-XX (SO-1121)	2	NR F	3	NR G, C	4	3	5	3	7	3	3	3	2
Plus-X	2	4	3	NR G	NR F	4	5	3	7	4	3	3	2
FP-3	NR F	NR F	6	4	3 NR F	4	6	4 NR F	7	4	4	4	2
Aero Infrared Hi-Speed	NR F	NR F	3	NR G	4	3	5	4	9	4	2	4	2
Aero Super-XX (SO-1166)†	2	4 NR F	3	3	3	3	NR F	4	5½	4½	3	4½	2½
Panatomic-X	2	2	3	NR G	¾	2	4	2	3	4	3	3	2
Pan-F	NR F	NR F	NR F	4	4 NR F	2	3	NR F	5	3	3	3	2
Contrast Process Pan	NR F	NR F	NR F	4	NR F	NR R	NR R	NR R	5	3	2	2	1½
Micro-File	1/8	2 NR F	¼	4	4	¼	½	3 NR F	3 NR M	3 NR M	NR M	NR M	1½ NR M
Telerecord	1/16	½	1	1 NR M	½ NR C	½	½	NR M	3	2	2	5	1¼

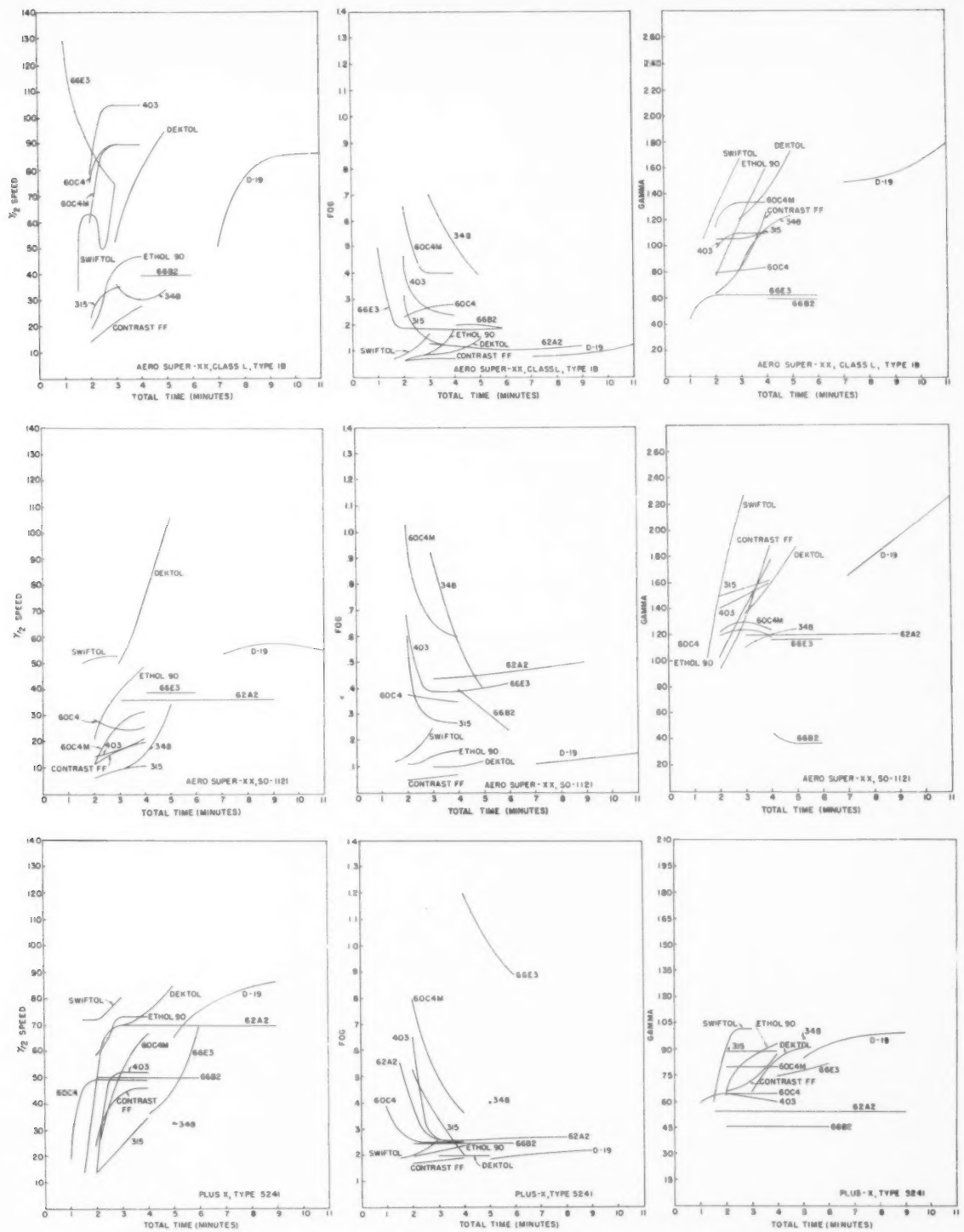
NR—Not Recommended
C—Not Fully Cleared
F—Fog Above 0.5
G—Gamma Below 0.5
R—Partially Reversed
M—Severe Mottling

* Not including washing and drying.

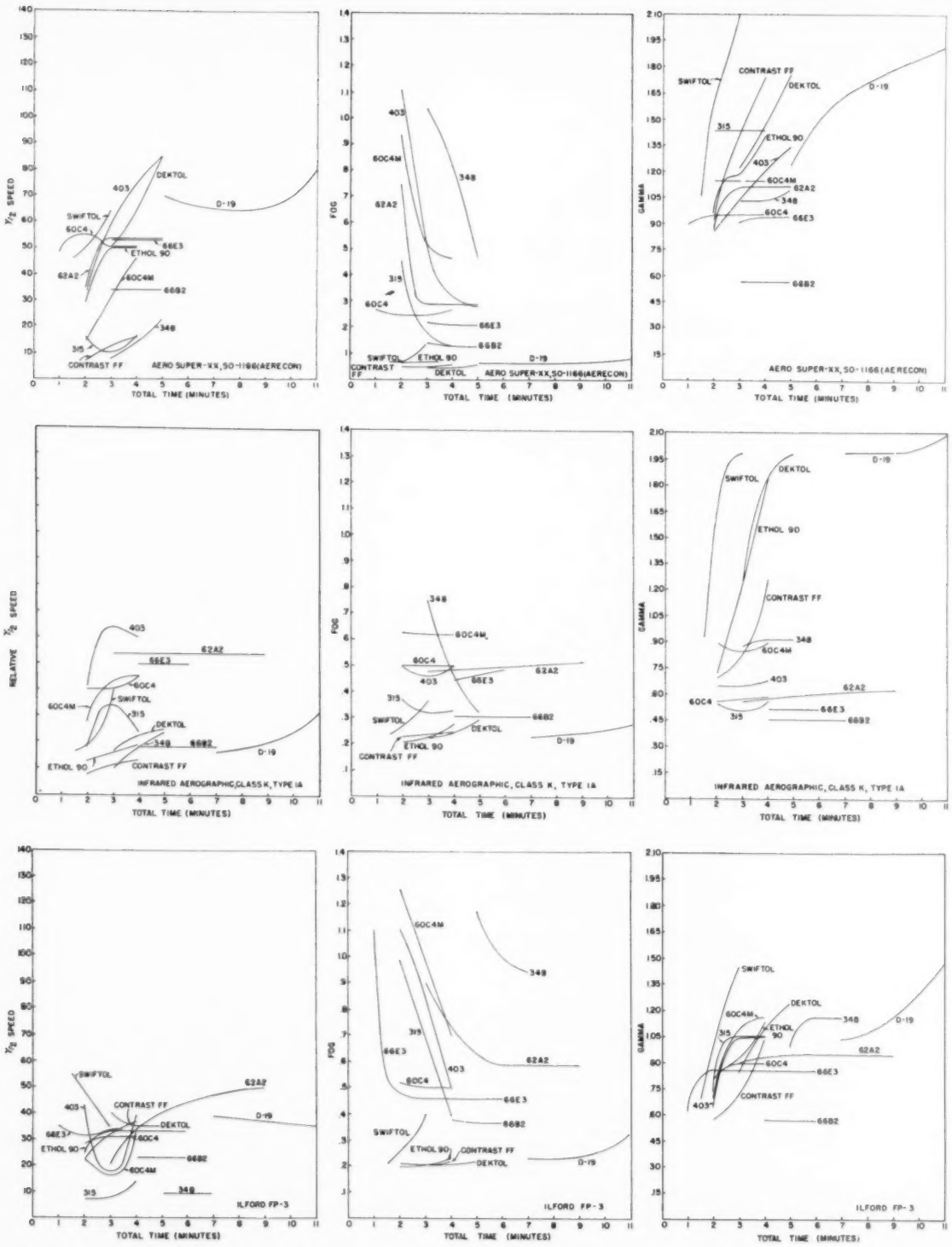
† Now designated by Eastman Kodak Co. as Plus-X Acrecon.



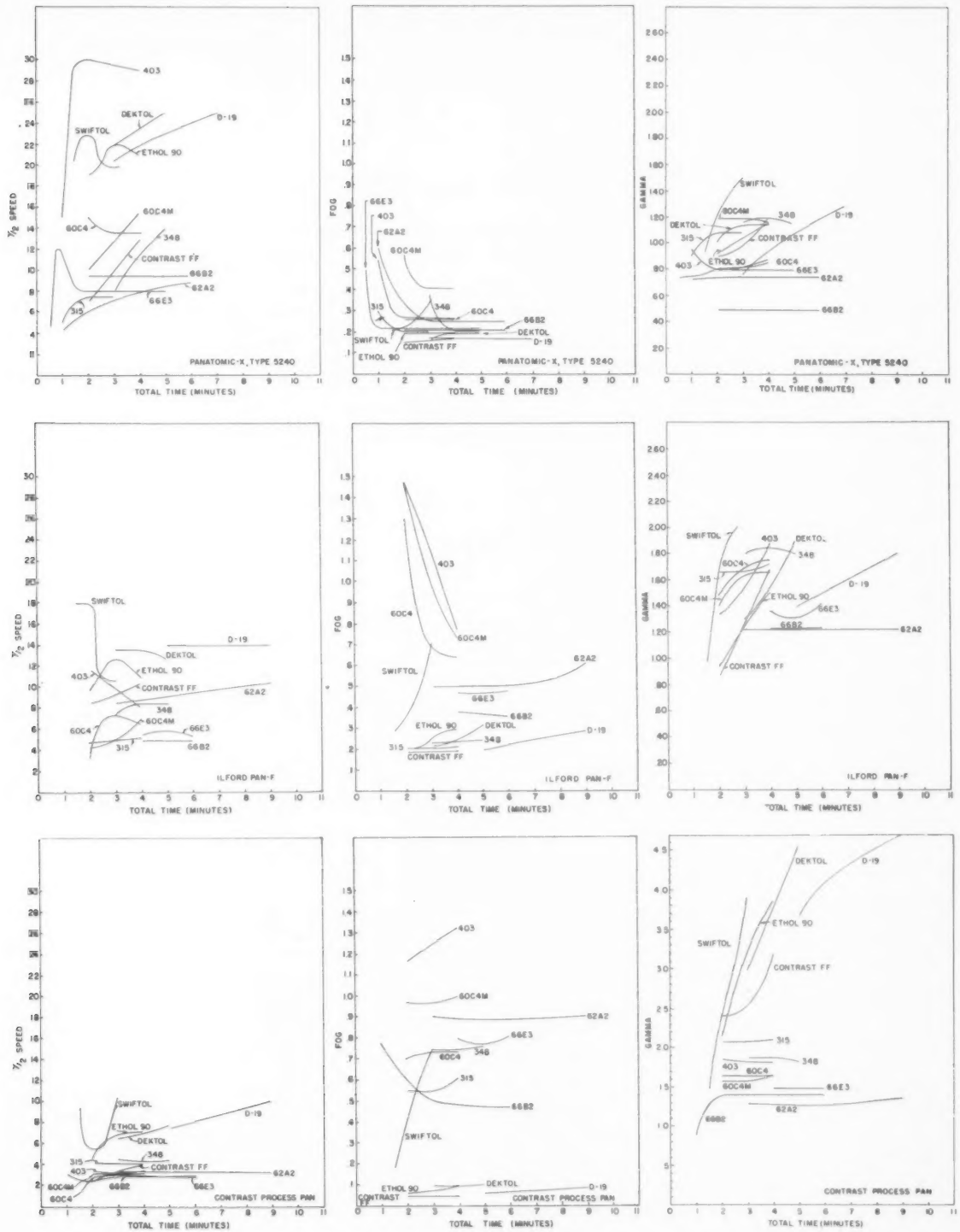
Figs. 2–4. Half-gamma speed, fog, and gamma vs total processing time for amateur (35mm) Tri-X, Aero Tri-X, and Ilford HP-3.



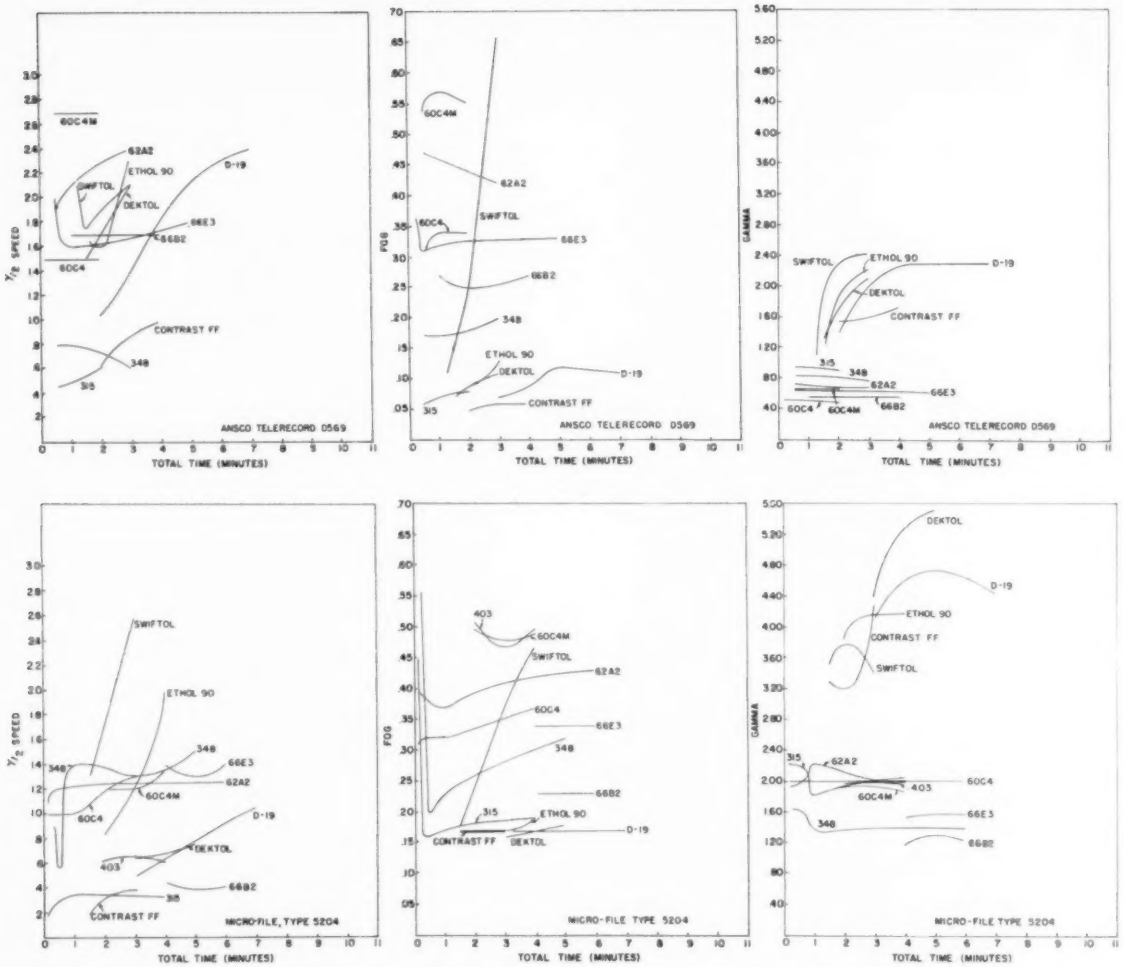
Figs. 5–7. Half-gamma speed, fog, and gamma vs total processing time for Aero Super-XX, Aero Super-XX (SO-1121), and Plus-X.



Figs. 8–10. Half-gamma speed, fog, and gamma vs total processing time for Aero Super-XX (SO-1166), Aero Infrared (relative), and Ilford FP-3.



Figs. 11–13. Half-gamma speed, fog, and gamma vs total processing time for Panatomic-X, Ilford Pan-F, and Contrast Process Pan.



Figs. 14–15. Half-gamma speed, fog, and gamma vs total processing time for Telerecord and Micro-File.

ing developer or monobath which provides maximum speed, optimum contrast, and negligible fog for all emulsions.

Of the rapid developers tested, Swiftol consistently proved most effective with a processing time of 2 minutes or less, but on prolonged development excessive fog occurred. Moreover, the dark-colored solution has a relatively short open-tray life and produces stains that are difficult to remove from the hands.

Although monobath processing offers the advantage of operational simplicity, there is a definite minimum processing time for each monobath–emulsion combination. Reasonable results are not achieved in shorter times because the emulsion has not cleared. Gamma is generally less than obtainable with a two-stage process since the competitive, simultaneous process of development and fixing reduces the amount of developable silver halide. Consequently, an energetic developing complement is required to produce sufficient image density before the fixing action predominates. High fog levels, however, usually result from the use of powerful developers, and a restrainer is necessary. Although the addition of antifogging compounds inhibits fog growth, it reduces emulsion speed and retards fixing action. The result is that the efficiency of both the developing and the fixing systems is lowered.

The delicate balance between development and fixing is further affected by both the chemical and the physical constitution of the emulsion. Silver chloride fixes faster than silver bromide, which in turn fixes faster than silver iodide. The presence of certain optical sensitizing dyes and hardening agents may further influence results. Thick emulsions did not normally produce optimum results at limited processing times since fixing proceeds at a slower rate than

for thin emulsions. It is notable that the very thin emulsion films Kodak Micro-File and Ansco Tele-record responded favorably to monobath processing.

The increasing use of thin emulsions in many photographic systems indicates that monobath processing can be used to advantage. Because of their tendency to form a silver sludge, however, monobaths appear best suited to "one-shot" applications, unless a suitable sequestering agent is incorporated in the formula.

It is evident, therefore, that for best results monobaths must be custom formulated, yet several of the amateur and professional black-and-white films included in this investigation yielded acceptable results with monobath formulas that have been disclosed.[1] With the information in hand, it appears possible to design a monobath that will work well with any given film within a specified time period.

Acknowledgments

The author desires to express his appreciation to Richard Oliver for technical assistance, to Harry S. Keelan for analysis of the monobath processing mechanism, and to Hutson Howell for direction and constructive criticism.

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1958 Annual Conference

6 to 10 October 1958

Manger Hotel • Rochester, N. Y.

The next Annual Conference of the Society has been scheduled for October 6 through 10, 1958, at the Manger Hotel (formerly the Seneca), in Rochester, N.Y. Planning for the Conference is well under way, with Ira R. Kohlman as Conference Co-ordinator. All inquiries about Conference matters should be sent to Mr. Kohlman, c/o Technicolor New York Corp., 533 West 57th Street, New York 19, N.Y.

An extensive papers program, including a special group of papers pertaining to the IGY, is being prepared under the guidance of Jerome S. Goldhammer, CBS Research Laboratories, 485 Madison Avenue, New York 22, N.Y. There will be exhibits of special photographic instruments and equipment. Chairman of the exhibits is Richard van Steenburgh, Fairchild Camera and Instrument Corp., Robins Lane, Syosset, L.I., N.Y.

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Flash Processing: A Rapid Access Photographic Technique

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A processing technique is described which not only retains the advantages of silver halide emulsions as to photographic speed and permanence, but also permits access to data within one second after they have been recorded. In flash processing, developer is applied in a very thin layer to the emulsion side only of the recording medium, which is then run over a hot platen. The heat applied through the dry back causes rapid development and drying. The record may then be viewed in daylight and is stable in a dry environment, although it may subsequently be stabilized or fixed, if desired. The equipment for flash processing is briefly described and some of the considerations in its design are reviewed.

In recent years there have been many attempts to shorten the time between the photographic recording of information and its presentation for visual inspection in permanent form. Stabilization processing and the use of monobaths come immediately to mind, and the application of print-out materials and xerographic techniques lead to the even more rapid presentation of results, but at the present time this is offset by a reduction in the available photographic speed. After nearly 100 years of service to photography, the combination of the silver halide emulsion plus chemical development still remains paramount where high photographic sensitivity is a consideration.

The greater sensitivity of silver halides is, of course, due to the amplifying action, whereby a group of relatively few silver atoms (the latent image) causes the deposition of a vastly greater number as development proceeds. No other amplifying effect of comparable magnitude has yet been found. The competing processes are insensitive by comparison, and, prior to the work about to be described, it was necessary to tolerate some of the delay and inconvenience of wet processing in order to retain the high sensitivity.

The present development came out of requirements in the field of oscillography, where the high-frequency response which is available only from mirror galvanometers dictated the use of silver halide emulsions, but the process, it is believed, is not limited to this application. The process is potentially usable wherever photographic materials sufficiently resistant to heat can be obtained.

In the practice of oscillography, it is frequently desirable to know what is going on as an experiment proceeds. For example, in order to induce some phenomenon, e.g., instability, in an airplane structure, it may be necessary progressively to increase the loading, the airspeed, or some other parameter until suitable indications are obtained from transducers on the structure. Because these transducers are normally connected to the oscillograph, it saves a great deal of time if it is possible to have a quick look at the record while the test is in progress. Parameters may then be varied without the delay of waiting for the record to be processed. The possibilities for savings in such operations as flight testing hardly need be stressed.

This requirement for quick access normally conflicts with other desirable features of a photographic oscillograph. When each trace is made by a light beam reflected from a mirror galvanometer, the attainable writing speed depends on both the light flux in the recording beam and the speed of the photographic process. While the writing speed may be raised by increasing the aperture of the galvanometer mirror, this also increases the mass and hence reduces the frequency response of the galvanometer. Thus the performance of the whole system depends critically on maintaining the high speed of the photographic process. This high speed formerly could be obtained only with materials which were wet-processed, and this in turn involved a considerable delay before the record could be examined. Results could not become available as suggested above while a test was in progress; the exposed roll of recording paper had to be transferred from the oscillograph to a processing machine, and in due course it emerged and could be examined.

The alternative processes which do not involve what is normally understood by photographic development may be used in an oscillograph to provide records with considerably shorter access time. But, because of their reduced photographic speed, all these

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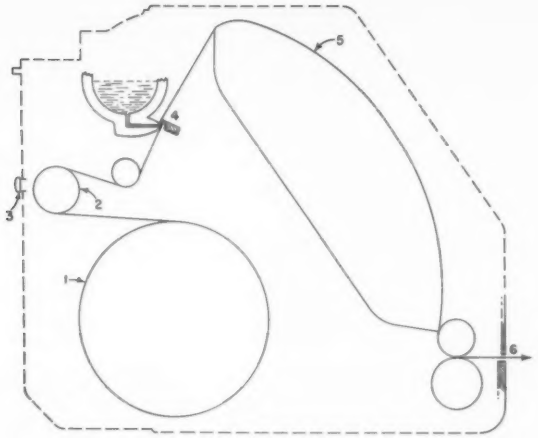

Fig. 1. Schematic diagram of the path of the paper in the magazine processor.

processes degrade the performance of which the instrument is otherwise capable, and they may have other disadvantages which need not be detailed here.

The requirement for a high-performance oscillograph with an access time of a second or less has been met by a method which involves the very rapid development and drying of the record prior to its emergence from the oscillograph magazine. This is only possible at such an elevated temperature that development and drying proceed simultaneously. The technique has therefore been termed "flash processing." The development process is arrested as the emulsion becomes dry, and the record is thereafter sufficiently stable to permit viewing in ambient light.

Development of a photographic record in contact with a hot drum was first described by Levenson,[1] and his method was applied at the Admiralty Research Laboratories, Teddington, England.[2] This pointed the way for further progress; but at that time it was apparently not possible to go beyond a record speed of about 2 inches per second. Further, a developer containing metol was used which is inferior to other developing agents in this application.

The present process operates at a speed of 25 or more inches per second and produces a fully developed and dried record at that speed. The paper path in an oscillograph "magazine processor"* is shown in Fig. 1. The paper web leaves the supply spool 1 and travels around the metering roller 2. Exposure takes place opposite the cylinder lens 3, which is actually not a part of the magazine, being integral with the oscillograph to which it is attached in place of the regular magazine. After exposure, the paper goes through the applicator 4, which spreads on the paper a layer of developer a few tenths of a mil thick. The paper is next run over a curved platen 5, which is maintained at a temperature somewhat above the boiling point, and here rapid development and drying occurs. Development has been observed in as little as 50 milliseconds. The processed record then emerges through a slot 6 in the case of the magazine, and is available for inspection. The total paper path between the exposure point and the exit slot is about 20 inches, so at 25 inches per second the access time is 0.8 seconds.

Figure 2 is a general view of the magazine processor attached to its oscillograph; Figure 3 shows the paper path over the curved platen; and Figure 4 shows the instrument with the platen swung out for loading the paper. In the design of a system of this kind many factors have to be taken into consideration, among them those discussed below.

* The Datarite Magazine Processor of Consolidated Electrodynamics Corporation, Pasadena, Calif.

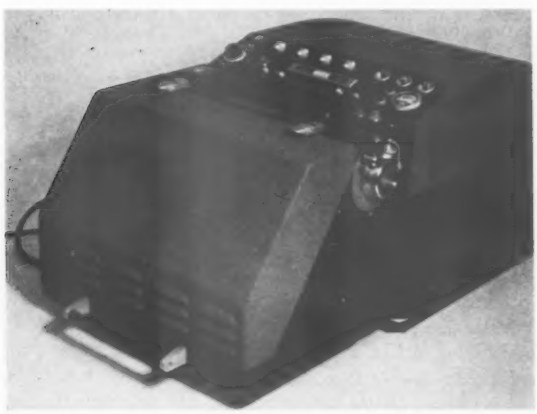

Fig. 2. General view of the magazine processor attached to Type 5-119 Oscillograph. The filler and sight glass for the developer may be seen on the right.

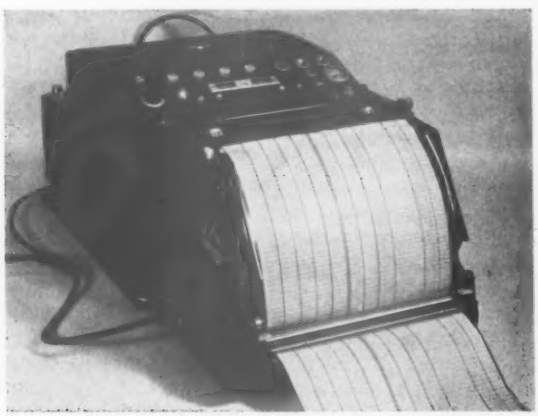

Fig. 3. The instrument with the cover off, showing the path of the paper over the curved platen.

Fig. 4. The platen swung forward to permit loading the paper.

The Developer

Developers for use in flash-processing equipment are somewhat specialized. The following partial list of requirements will serve to outline the problem. Development and drying must occur in well under one second; besides defining the minimum acceptable developing rate, this requirement limits the amount of water which may be used. The developer and its residues should not release any objectionable fumes when heated on the platen, neither should it contain allergens, such as metol. The residues should not contain anything which is highly colored, or which will become so after oxidation, because they have to remain in the paper and so would contribute to the background fog. Further, although extreme speed of operation is called for, the developer must not cause appreciable chemical fogging of the emulsion on the hot platen. The record should be as stable as possible, but if volatile components are used in the developing solution, they must remain in the hot emulsion long enough to fulfill their purpose.

It is thought that the unusual method of application of the developer, that is, spreading a low-viscosity film on the emulsion side of the dry paper only, may help the situation in one respect. The developer is permitted to penetrate the emulsion with great rapidity. The exact mechanism by which this occurs undoubtedly varies with the type of emulsion and the type of paper support. The situation is similar in spray-processing of paper materials, but there are important differences, such as the increased aeration and the large amount of solution involved in spray-processing. The present method is characterized by extreme economy of solution and negligible aeration.

As might be surmised, considerable experimentation was necessary to evolve a developer which came close to performing satisfactorily. For example, it was found that developers containing metol or metol and hydroquinone, when formulated to operate at the high speed required in this equipment, did not produce acceptably fog-free backgrounds. In some cases, the background was light enough when the record was first processed, but it tended to darken unduly later. The solution used in the magazine processor at present is basically a phenidone formula, modified to suit the type of recording paper used.

There are many possible variations within the basic formula. If the alkali used in the developer decomposes thermally, as do, for example, the tetraalkyl ammonium hydroxides, the pH of the system will drop as development on the hot platen proceeds; if this alkali is chosen so that full development takes place before decomposition, a record with good contrast and a modified stability pattern is obtained. Normally a flash-processed record is most vulnerable to the marks caused by moisture from perspiration, and so on, in about the first half-hour after processing. Thereafter, it becomes progressively more stable at a rate determined by such factors as the ambient relative humidity, the quality and amount of incident radiation, and the developer formula used. During this time, the developer is being oxidized and the alkali is being partially neutralized by atmospheric carbon dioxide. The use of a "fugitive" alkali was cited previously as a means of improving the record stability. It is also possible to use other fugitive components for the same purpose. For instance, materials which are destroyed by heat, such as reductone or hydrazine derivatives, may be used as the developing agent. In the processed record, which has been heated, they are no longer present. Again, a reducing agent of this type may under certain conditions be used as a preservative for a combination of more conventional developing agents. When processed, the preservative is no longer present so that the oxidation of the residual developing agents in the record may proceed more rapidly.

The possibility remains of using a monobath for flash-processing. It would be necesary not only to make the stabilizing component of the solution work extremely rapidly, but also to make it stable and fog-free at the high temperature used. A solution with these characteristics is not yet available. A further possibility exists of adding one or more applicator stages for the purpose of applying a separate stabilizing solution. One of the main drawbacks to this scheme lies in the increased power required for evaporation of the additional water which has to be added along with the stabilizer; and the penetration of the stabilizer into the emulsion will be considerably slowed unless the record is dried between the developer and the stabilizer applications. For these

reasons, it would appear to be difficult to get a stable record by film application of stabilizer.

A flash-processed record, however, does have an advantage in the convenience with which it may be fixed. Once it has been processed by this method, those portions of it which are of sufficient interest may be treated in an acid hypo bath in full daylight. No darkroom is needed for any part of the operation. Furthermore, during this after-processing, any photolytic silver formed by the action of light and moisture is largely dissipated, so that a truly black-and-white record results.

Application of the Developer

It is possible to spread a liquid on paper in a variety of ways which may be divided into three broad categories. There are wicks, sponges, and other arrangements using porous materials; there are rollers; and there are weirs, slits, and similar devices. When it is necessary to spread a thin, uniform layer, the choice of methods is severely limited. The choice is still further restricted when this layer has to be applied in a fraction of a second and at a paper speed which is subject to variation. Wicks and sponges tend to give a nonuniform coat, due to the uneven squeegee action of their trailing edges. Rollers also give a streaky layer, but in applications where time permits, the layer may even itself out before drying. With both these methods, a doctor blade may be used to level the coat if sufficient material has been applied. In the case of photographic developer, this technique is to be avoided for chemical reasons. Any excess of material exposed to air merely aggravates the oxidation problem — in the case of rollers, there is a free surface in the reservoir in which a moving roller is constantly entraining air; and a wick or a sponge provides additional surface for the penetration of oxygen. Furthermore, solid deposits tend to build up on such devices during the intervals between operation.

A narrow slit, which may be likened to a drawn-out pen nib, has none of these drawbacks and it may be made to apply a thin, even layer at widely varying paper speeds. The applicator in the magazine processor consists of such a slit associated with a back-up bar which controls the angle of wrap of the paper around the slit jaws. The wrap is important for controlling the coating thickness. At high speeds the inertia of the paper causes it to balloon out from the trailing edge of the slit if a back-up bar is not used. Firm contact between the paper and the slit is also necessary at low speeds in order to prevent excessive coating thickness and leakage.

Drying the Paper

One of the principal differences between this process and that of Levenson is that in the present case the paper is not immersed in the developer, but instead receives a very thin layer on the emulsion side only. Thus drying is not the problem it would otherwise be. For one thing, less heat has to be supplied to evaporate the water, and for another, the paper may be made to slide over a curved heated platen instead of being wrapped around a drum which has to rotate because the paper is wet and sticks to it. This simplifies the heating problem, saves space, and produces a more convenient geometrical layout. A significant proportion of the applied water in the developer is able to equilibrate with the paper support and thus the heat required for evaporation is still further reduced. When everything is taken into consideration, one kilowatt into the platen is found capable of drying 12-inch-wide paper at about 6 to 7 inches per second on a continuous basis. If the paper is run faster than this, the platen gives up some of its stored heat and its temperature drops somewhat. Allowance has been made for this in the design, so that the speed may be jumped to 25 inches per second for short bursts of up to 40 feet. Provision may be made to increase the wattage input to the platen, but the standard model has been arranged so that both it and the associated oscillograph may be operated together from one 15-ampere outlet.

Another solution to this problem lies in the use of a platen containing a material which melts at the operating temperature. If a material is chosen with a latent heat of fusion of 40 calories per gram or more, it is possible to store sufficient heat in the platen to process and dry a 400-foot roll of 12-inch-wide paper at 25 inches per second without a break, provided a short "rest period" is available between rolls for reheating. A suitable heat-storage material does not itself have the heat conductivity necessary for transfering the heat to the platen surface at a sufficient rate, so that the hollow platen has to be constructed with numerous internal fins or vanes for this purpose. The fusible material then becomes disposed in thin sheets between the metallic vanes. A platen designed along these lines tends to be complicated and rather heavy, and so it is expected to be applicable only in special circumstances.

The platen accounts for the major part of the length of the paper path in the processor, and so contributes decisively to the access time at any given paper speed. The length of the platen is determined by the time required for the necessary conduction of heat from the platen into and through the paper at the highest paper speed at which the processor is to run. Hence the platen cannot be made very short in the interest of access time at low speeds because at high speeds it would not give up sufficient heat for drying the paper. At the cost of some mechanical complication it should be possible to arrange for a variable-length platen, or for a variable wrap of the paper around the platen. At first sight this might seem to be advantageous also from the point of view of improving control over the development process at different paper speeds; but as fogging due to heat may be averted by chemical means, it seems desirable to avoid mechanical changes in the processor which would have to be made simultaneously with speed changes in the oscillograph.

Conclusion

It is believed that embodiment of the flash-processing technique in an oscillograph magazine processor is a decisive step in what may become a widespread application in photographic processing technology. In the magazine processor, the method has been simplified as much as feasible. This has been possible because a line image on paper of good contrast and stability has been the only requirement. Work presently under way is expected to lead to commercial application of flash-processing to the production of continuous-tone images on paper and film.

Acknowledgment

Grateful acknowledgment is made to Frank Bumb, Michael Godfrey, and Howard Lyon, all of whom made significant contributions in the course of this work.

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PHOTOGRAPHIC SCIENCE AND ENGINEERING
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Design of a Lightweight Aerial Panoramic Camera

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A 3-inch lightweight aerial panoramic camera containing rotating double-dove prisms weighs 52 pounds loaded with 1,000 feet of 70mm film. This high-resolution camera is, in effect, a self-contained system with image motion compensation, intervalometer, automatic exposure control, data recording, and a master control circuit to insure completely fail-safe operation. The camera has automatic sequencing, adjustable for adjacent or stereo overlap, and provides successive lateral sweeps for horizon-to-horizon coverage of an entire mission. A pulse signal generated with each exposure is available for synchronization of associated equipment.

The purpose of photographic aerial reconnaissance is to furnish maximum information about natural and man-made objects with minimum equipment both in the aerial vehicle and on the ground.

The salient factors affecting performance of a reconnaissance system have been defined by Goldhammer[1] as:

1. Quality of image
2. Quality of coverage
3. Adaptability of reconnaissance vehicle characteristics
4. Time lag and apparatus requirements for data extraction

The most widely used present system, the Tri-Metrogon System[2] utilizes three cameras, one vertical and two oblique, equipped with wide-angle lenses that yield horizon-to-horizon coverage across the line of flight. In this system, the *quantity* of coverage has been satisfied to the severe detriment of the other three requirements. The *quality* of the images is restricted by the inevitable deficiencies in resolving power and speed of the wide-angle lenses. The great weight and the space and window requirements of the three-camera battery limit its *adaptability*, particularly to small, already-crowded jet aircraft. Finally, film processing and image interpretation are complicated by the necessity for separate handling and matching of the three sets of negatives and their discontinuous scale relationships. Thus the *time lag* increases.

Although no single system satisfies completely all four factors simultaneously, it will be shown that the transverse panoramic camera system imposes fewer and less serious limitations than other systems available heretofore.

The Panoramic Principle

The classic methods of panoramic photography involve rotation of either the lens or the entire camera about the nodal point of the lens through an appropriate angle of scan. In this way, a conventional, high-resolution lens with modest field of view can be used to produce extreme wide-angle photographs. One such system was explored in an experiment by the Boston University Physical Research Laboratory.[3] It involved a strip camera mounted outside of the aircraft and geared in such fashion that the film and image moved synchronously when the camera was rotated to scan the object space.

A more sophisticated scanning method was conceived by James G. Baker; it employed a rotating dove prism mounted below a slit-type camera in which the film could be transported past the slit in synchronism with the moving image. Of course, in such a system the camera itself can be mounted inside the aircraft and only the rotating prism need protrude outside. Moreover, the prism can be enclosed in a small transparent dome.

A reconnaissance camera of this type, the Model E-1, was built for the U.S. Air Force by the Perkin-Elmer Corporation. It yielded excellent photographic results and proved the soundness of the rotating-prism principle. The dimensions and weight of the E-1 camera, however, were formidable. For example, its prism weighed more than 40 pounds, or more than the complete Model 501 to be described. The lens had a maximum aperture of $f/8$ and a focal length of 48 inches. Film capacity was 5,000 feet of 18-inch

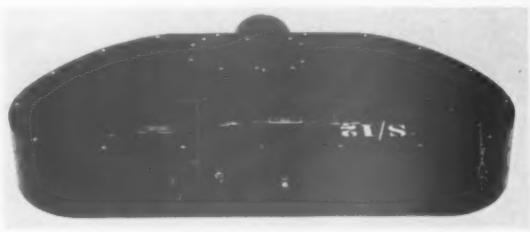


Fig. 1. The Model 501 Lightweight Transverse Aerial Panoramic Camera.

Presented at the Annual Conference, Asbury Park, N.J., 11 September 1957. Received 19 August 1957.

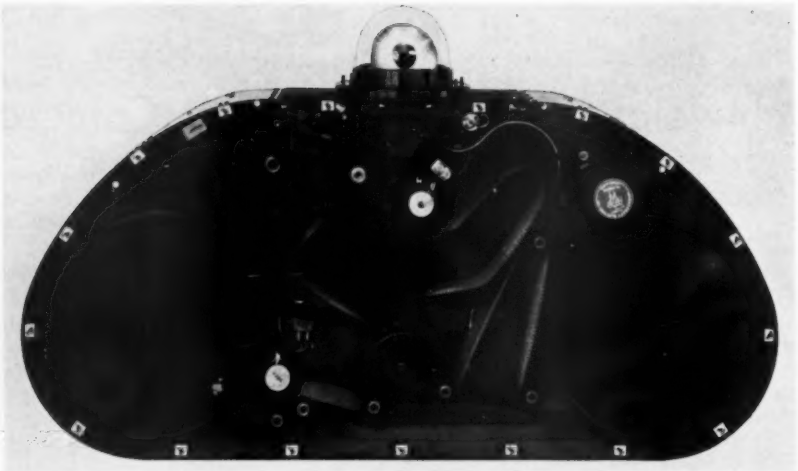


Fig. 2. Panoramic camera, film cover removed.

wide material, with a total weight of 600 pounds, and the image format was 18 × 151 inches, or 21° × 180° per scan. Yet the camera was capable of out-performing a battery of conventional cameras of even more formidable aggregate proportions and weight.

The Model 501 Lightweight Transverse Panoramic Camera

The 70mm lightweight transverse panoramic camera is a much smaller and significantly improved successor to the E-1 camera. It meets desired performance standards better than current multi-camera systems because:

1. Since the lens need not have a wide field of view, maximum emphasis can be placed on image *quality* and speed.

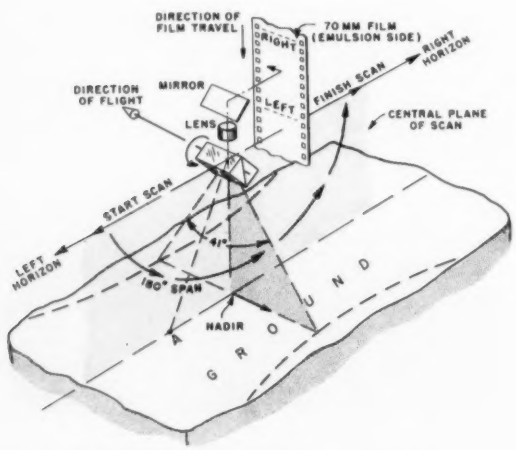


Fig. 3. Schematic diagram of the scanning system.

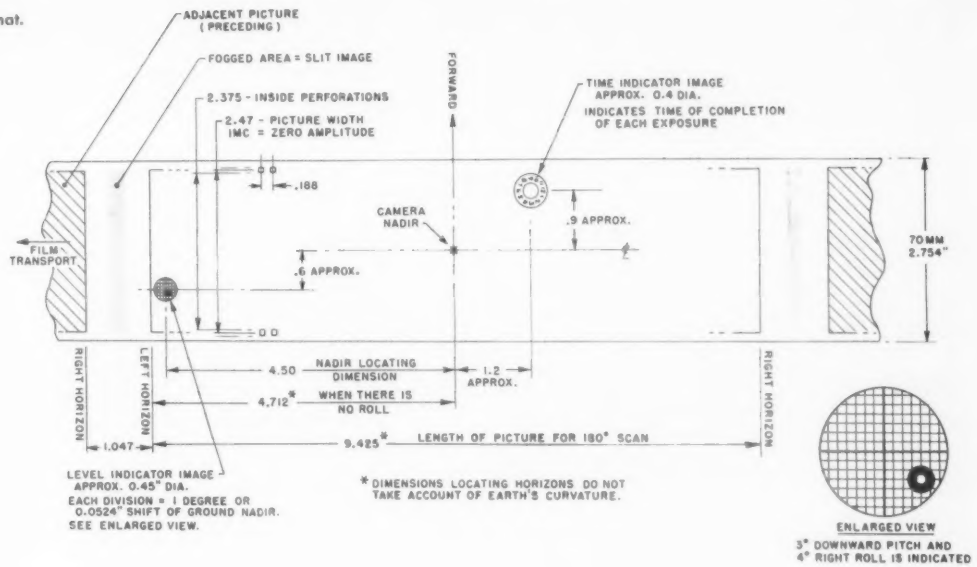
2. Fully graded image motion compensation (IMC) is built into the mechanism.
3. Complete transverse *coverage* as well as large film capacity is provided.
4. *Adaptability* is achieved through compact, lightweight construction and automatic operation.
5. The *time lag* for interpretation of results is short, since each element of the matrix covers the ground from horizon to horizon with continuity of scale. Also the scale of overlapping portions of adjacent frames is such that a simple stereo viewer may be used directly on the negatives or contact positives to obtain good perspective over the entire format.

The camera is unusually thin (Fig. 1) and is easily mounted by means of its dome flange studs. The main structural member of the camera is an upright casting plate whose double rim forms two compartments. This plate supports the film spools and sprockets on one side (Fig. 2), and the drive mechanisms and control components on the other side. The compartments are covered by lightweight, flat aluminum panels that are easily removed for loading or servicing. The lower part of the casting is formed into a mounting flange that also supports the glass dome containing the scanning prism. The operating controls are mounted on a recessed control panel at the top of the camera.

Hose connections are provided in order that dry gas may be pumped into the dome. To maintain low humidity during pressure equalization while the camera is in use, a desiccator and breather tube assembly are mounted on the rear cover. Also, metal radiation shields are mounted in the dome to localize condensation on the unused portion of the interior surface. Other camera specifications are summarized below.

Format . . . . . .Angular coverage, 42° × 180°.
Weight (unloaded). .40 pounds.

Fig. 4. The film format.


ADJACENT PICTURE (PRECEDING)
FOGGED AREA = SLIT IMAGE
2.375 - INSIDE PERFORATIONS
2.47 - PICTURE WIDTH IMC = ZERO AMPLITUDE
FORWARD
TIME INDICATOR IMAGE APPROX. 0.4 DIA.
INDICATES TIME OF COMPLETION OF EACH EXPOSURE
.188
CAMERA NADIR
.9 APPROX.
70MM 2.754"
FILM TRANSPORT
.6 APPROX.
RIGHT HORIZON
LEFT HORIZON
4.50 NADIR LOCATING DIMENSION
1.2 APPROX.
4.712* WHEN THERE IS NO ROLL
1.047
9.425* LENGTH OF PICTURE FOR 180° SCAN
RIGHT HORIZON
LEVEL INDICATOR IMAGE APPROX. 0.45" DIA.
EACH DIVISION = 1 DEGREE OR 0.0524" SHIFT OF GROUND NADIR.
SEE ENLARGED VIEW.
* DIMENSIONS LOCATING HORIZONS DO NOT TAKE ACCOUNT OF EARTH'S CURVATURE.
ENLARGED VIEW
3° DOWNWARD PITCH AND 4° RIGHT ROLL IS INDICATED

Dimensions	$37^1/_2 \times 18^1/_2 \times 7^1/_2$ inches; $5^1/_2$ inch diameter mounting hole required.
Power Requirements	24-30 volts d-c, $^3/_4$ ampere continuous load, with intermittent peak loads to $4^1/_2$ amperes.
Film Capacity . . .	1,000 feet × 70mm, standard base film, MS 33525 perforation on special spools, with leader.
Film Consumption .	10.472 in. exposure; threading may be accomplished on open-ended sprockets, without feed-through.
Objective	3-inch, *f*/6.3 Orthometar (6-element) Coated Lens.
Filters	Built-in Aero Red, Minus Blue, and Clear.

Optics

The scanning prism is composed of two dove prisms whose diagonal faces are aluminized and cemented together (Fig. 3). A very high degree of accuracy is required in manufacturing and mounting to achieve good resolution and freedom from double images at the center of scan where both prisms are operative. Since the image-forming light is reflected by the aluminized prism faces, the scan rate equals twice the angular rate of prism rotation, i.e., a 180° scan is completed in 90° of prism rotation. Moreover, the image displacement is linear and constant at the rate of one focal length per radian of scan, or 3π inches per 180°, which is 9.425 inches. In the Model 501 camera, the image is projected through a stationary slit which may be varied in width according to the desired exposure.

The filter cage and an additional mirror are located between the lens and the focal plane. The front surface of the mirror is partially coated to offset $\cos^4$ light losses and yield uniform exposure across the film. The mirror also corrects the image which has been inverted by the prism. The transmission of the entire optical system is approximately 50 per cent with an effective speed of T-8.

A special problem in the manufacture of the Model 501 camera is that of matching exactly the effective focal length of the optical system to the fixed ratio between prism and film sprocket, and also that of matching and aligning the lens, prism, and dome to secure high resolution. Since the dome itself participates in image formation, it must be of good optical quality.

The arrangement of the optical parts is depicted in Fig. 2. The prism is located in the center of the dome and mounted to scan counter-clockwise. The lens is immediately above the prism at about dome flange level, and is mounted through a horizontal partition which seals off the dome area. Immediately above the dome and within the camera body is a housing which contains the mirror and filter cage. A filter selector knob is located on its outside. The slit jaws are mounted at the right side of this housing close to the film sprocket and focal plane assembly.

During a scan cycle, the film passes around the sprocket assembly in counter-clockwise direction and passes the level indicator where a level bubble is imaged onto it by means of a rotating mirror at the instant of scanning nadir. The nadir point of the photograph can be determined from this bubble image with the aid of a grid (Fig. 4). Also, the face of a watch is recorded at the completion of each scan.

Extraneous light, which is troublesome in rotating prism systems, is minimized by light baffles and by a

Fig. 5. Single-frame photograph showing horizon-to-horizon coverage.

masking mechanism that gradually decreases the prism aperture as it approaches the limits or horizon portions of each scanning cycle.

Film Mechanisms

The film is transported by means of the scan sprocket, in synchronism with the image. The sprocket itself comes to rest between exposures but the prism and intervalometer are in continuous operation.

Because of the nature of the prism design, only one scan is made per whole turn, though the scan itself is completed in one-quarter turn. A clutch controls the intermittent film motion and the timing function; it is actuated by the intervalometer in proper phase with prism rotation.

One turn of the sprocket advances sufficient film for one 180°-scan image and a narrow band between frames. It is unnecessary, therefore, to close the focal plane slit between exposures, since only the narrow, interimage area is fogged. During exposure, the film moves through the focal plane under tension and, disengaged from the sprocket teeth, over a slightly backward-curved plate; it then passes over two idler rollers, one of which is spring-loaded.

The design requirements for the prism and sprocket drive are severe, in order to achieve the desired resolution of 40 lines/mm. At this level of resolution, the line width and space between lines totals 0.001 inch. If image blur of 0.0003 inch is considered tolerable, the permissible differential motion of image and film can be computed for any given slit width. For example, with a slit width of 0.188 inch, which yields the maximum exposure time of $^1/_{55}$ sec, the permissible error in relative motion of film and image is

$$\frac{.0003}{.188} \times 100\% = 0.16\%$$

This is the total allowable error which is the sum of errors in the pitch of film perforations and sprocket teeth, and in the gearing between the sprocket and the prism. To stay within this permissible error, the teeth for the special sprocket are manufactured with tooth-to-tooth and involute accuracies of 0.0001 inch, the gears are Class 3, shaped and shaved, and Class 7 ball bearings or precision journal bearings are employed at all critical points.

The prism-drive and film-sprocket system is driven by a governor-controlled d-c motor and precision gear box at 120 rpm. The output of the gear box is transmitted to the prism-sprocket system through one of a group of interchangeable gear pairs that provide speeds as slow as 2 seconds and as fast as $^1/_4$ second for a 180° scan.

Film exposed during the scan is transported between storage loops as is customary in motion-picture practice. The feed and take-up spools are moved only between scans to restore the loops to pre-exposure conditions.

A separate d-c motor drives the take-up reel, but not the feed reel or the metering sprocket which are rotated by the film. A latch and a spring-loaded cam,

mounted on the metering sprocket shaft, limit sprocket rotation to one revolution. Since the metering sprocket is the same diameter as the scan sprocket, the amount of film metered is equal to the amount exposed. The drive mechanisms for transport and metering are controlled electrically by a sequential relay circuit.

Intervalometer (Automatic Sequencing)

The intervalometer triggers the clutch of the film-transporting sprocket at manually preset intervals. The minimum interval is 2 seconds for a ratio of altitude to speed of 11 feet per knot, e.g. 1,100 feet altitude and 100 knots ground speed.

A switch synchronized with the continuously-rotating scanning prism generates a continuous train of pulses. The setting of the exposure interval switch determines how many pulses are counted before the intervalometer connects the coil of a relay and power line, to start the camera operating cycle. The scanning prism switch then clears the intervalometer for the next count.

Automatic Exposure Control

The camera exposure is controlled automatically from photovoltaic cells mounted facing downward in the dome on either side of the scanning prism. A signal proportional to scene brightness is used in a relay-servo and follow-up system to automatically control slit width and thus the amount of exposure. Since the correct slit width also depends on film speed, filter factor, and scan time, a six-position range-control switch has been included.

The slit width is varied by a cam that is actuated by a d-c servo motor. An ultra-sensitive relay system is used to amplify the low level error signal in a null-bridge circuit and furnishes pulses to the servo motor that tend to reduce the error to zero. Any change in average scene brightness causes an unbalance of the bridge and hence an automatic re-adjustment of the slit width. The slit width may be preset manually at a fixed value as an alternative mode of operation.

Image Motion Compensation

IMC is accomplished by harmonic axial displacement of the focal backing plate and transport sprocket over which the film travels during exposure. The movement is synchronized with the scanning prism and generated as a function of instantaneous scan angle (graded IMC). The displacement amplitude depends on the scanning speed and the altitude/speed ratio of the aircraft and is adjustable up to 0.07 inch. This corresponds to 0.90 inch per second image velocity at $^1/_4$-second scan time. True compensation is thus available down to 5.6 feet per knot.

Performance

A single-frame photograph taken over Jamaica, Long Island, N.Y., from an F9F Reconnaissance Jet at an altitude of 12,800 feet is reproduced in Fig. 5. The scale at the center is 51,200 :1 and vehicles can be identified. The scale at 30 degrees below the horizon is 102,400 :1, and vehicles can be counted at a distance of 4.2 miles from the center. Bridges can be identified at 12 miles, and the geography of shorelines, rivers etc., extends to 40 or 50 miles. Effective exposure time for the photograph in Fig. 5 was 1/400 second with the minus-blue filter, and image resolution equals 40–50 lines/mm.

Safety Devices

The camera controls are interlocked to insure completion of a cycle regardless of changes in control settings. If a film break occurs, the drive motor is shut off and a warning light flashes. Should power fail during either a film-scan or a film-metering sequence, the mechanisms will complete the cycle upon restoration of power.

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PHOTOGRAPHIC SCIENCE AND ENGINEERING
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A New 70mm Automatically Controlled Aerial Camera

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The Model P-220, which has been developed from the Model P-2 camera, is a 70mm camera used for high altitude jet aircraft weather survey operations. It can be pulse operated at rates up to 5 1/2 frames per second and has a focal plane shutter giving speeds of 1/500, 1/1000, and 1/2000 second. A 38mm f/4.5 Zeiss Biogon lens is coupled to an automatic exposure control consisting of a transistorized computer. The entire camera system is compensated to operate over a wide range of voltage and temperature variations and, with 50 feet of film, it weighs 9 pounds 10 ounces.

The P-220 is a new 70mm camera which incorporates many of the engineering principles applied in the P-2 camera[1] manufactured for the U.S. Air Force. The differences, however, are rather important. The new version permits use of the wide-angle Zeiss Biogon 38mm $f/4.5$ lens; it can be pulse-operated at up to $5\frac{1}{2}$ frames per second; it has an automatic iris control rather than the coupled iris-shutter of the original model; it has a frame marker for indentifying single exposures; and it provides an output signal pulse to monitor each picture cycle.

One of the first applications of the new camera has been high altitude weather photography. The Biogon lens is ideally suited for this service since it covers 93 degrees across the diagonal and 70 degrees on the sides of a $2\frac{1}{4} \times 2\frac{1}{4}$-inch picture.

The complete camera system consists of the Model P-220 camera, a magazine, a radio noise filter, a sensor (light detector), and a computer.* These components, connected by cable, are shown in Fig. 1, together with the usual cover accessories and a standard alignment plate. It will be noted that the sensor unit is mounted directly on the camera so that its angle of view is the same as that of the main objective lens. The pulse required to trigger the camera should have a nominal amplitude of 24 volts, a duration of 100 ± 30 milliseconds and a repetition rate of up to $5\frac{1}{2}$ cycles per second. If the control circuit is continuously energized, the camera will operate at a runaway speed of 6 frames per second.

Shutter

The focal plane shutter design for the Model P-220 camera is essentially the same as that of the earlier Model P-2. Three speeds, 1/500, 1/1000, and 1/2000 second, are provided, plus an OPEN position. The main and capping curtains are of stainless steel and are chemically blackened to reduce reflection within the camera body. The drive mechanism controls the shutter cycle and actuates the gear train to advance the film in the magazine between exposures. The shutter cycle of cap, wind, uncap, release, and expose can be repeated up to 6 times per second. The view of the camera in Fig. 2 reveals the mechanism for operating the shutter and driving the film transport system. The shutter curtains and the aperture plate of the magazine can be seen in the views of the camera and magazine in Fig. 3. The drive gear between the camera body and the magazine is visible at the bottom of the shutter housing.

Bore-Sighting

Bore-sighting is easily accomplished by using an aligning plate (shown in Fig. 1) in place of the camera

Fig. 1. Complete P-220 camera system. Shown are the camera, magazine, radio noise filter, computer, sensor, lens filter, lens cap, bore-sighting cover, and magazine cover.

Presented at the Annual Conference, Asbury Park, N.J., 11 September 1957. Received 13 September 1957.

* An intervalometer is not included in the Maurer P-220 system, since it is usually a part of the airframe equipment.

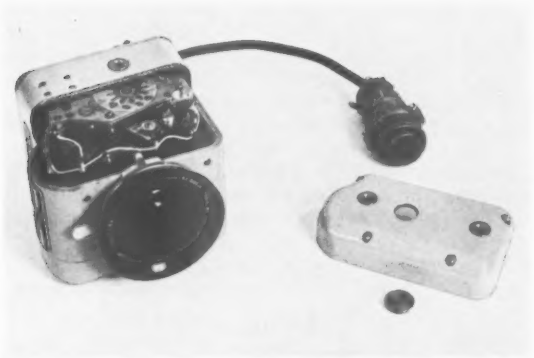

Fig. 2. Shutter and film transport mechanism. The shutter speed adjustment lock, hand crank screw cover, and hand crank shaft can be seen.

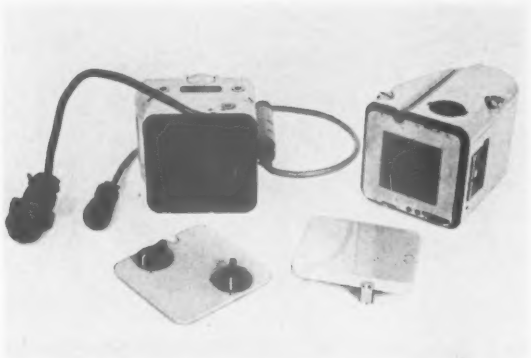

Fig. 3. Camera shutter and magazine aperture. The focal plane shutter, aperture plate, camera cover, magazine cover, and magazine drive gear can be seen.

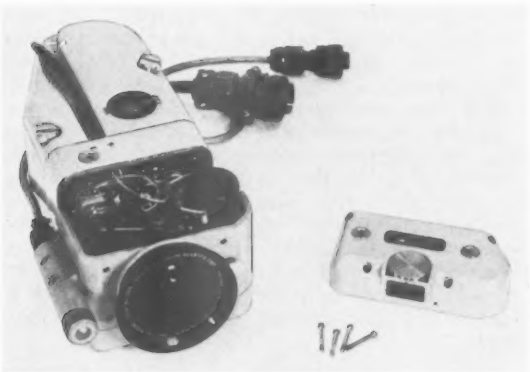

Fig. 4. Lens iris operating mechanism. Shown are the solenoids DPDT switch, positioning commutator, drive motor, and sensor.

cover. This plate contains a circular ground-glass screen positioned at the focal plane of the objective lens and centered on its optical axis. With the lens iris wide open and the shutter set to OPEN, the curtain slit may be positioned in the center of this glass screen by turning the hand-cranking shaft located under the screw plug shown in Fig. 2. No special tools are required since a ten-cent coin will fit the plug slot and the shaft notch.

Diaphragm Control

The basic mechanical drive and the electrical control of the lens iris were patterned after the proven P-2 system. The controlled members always follow the direction of motion of the control. This is an important feature in an automatic iris control system which is expected to yield optimum exposure at all times. The iris operating mechanism (Fig. 4) consists essentially of two solenoids, each with three windings to operate a DPDT switch, a positioning commutator, and a small permanent-magnet motor. The solenoids are controlled by the computer which responds to the sensor's signal, as will be described later.

Frame Marker

Identification of individual frames, or groups of frames, has been provided for by means of a small spot image exposed onto each selected frame with the aid of a pulsed lamp that is located behind the pinhole aperture of an appropriate housing. A suitable pulse timer may be used to control the frame-marking circuit which operates from the 28-volt power supply.

Output Signal

The camera system also includes a control circuit to operate an external signal lamp or counter system for remote checking or surveillance of camera and intervalometer performance. This circuit has a 0.25 ampere capacity at the regular power supply voltage.

Automatic Exposure Control

The exposure control will operate over a light level range of 250 to 15,000 foot-Lamberts. This is achieved by taking advantage of film latitude and by selecting a practical step control function.

The camera is equipped with a manual selector control, called diaphragm range selector, with three positions, A, B, and C. Each of these ranges has three discrete iris settings which, in accordance with existing practice, are designated as Bright, Hazy, and Dull (Fig. 5). Thus nine iris settings are available, as indicated in Table I.

TABLE I
f/Numbers

Range	Bright	Hazy	Dull
A	12.7	7.6	4.5
B	16	9.5	5.6
C	22	13.3	8

Fig. 5. Camera and computor. The diaphragm range selector and the computer range selector are shown.

A main problem in the development of an automatic exposure control system is that of establishing proper correlation between the expected range of subject brightness values and the range of film speeds to be used with the ranges of available shutter speeds and lens aperture settings. Since the P-220 camera has a series of discrete iris settings, it was necessary to determine first what maximum subject brightness would be encountered and to fix the minimum camera exposure accordingly. Next, the subject brightness values had to be determined that would yield optimum exposure at the *f*/stop settings given in Table I.

The sky brightness at high altitudes frequently reaches the 10,000-foot-Lambert level. Since clouds have a reflective factor close to unity, it was decided to consider 10,000 foot-Lamberts as the maximum brightness and Table II was established on this basis.

TABLE II

Range	Bright*	Hazy*	Dull*
1	3,260	1,150	410
2	5,660	2,000	710
3	9,600	3,450	1,250

* All values are in foot-Lamberts.

It was determined subsequently that 2,000 foot-Lamberts is, in fact, the average brightness of subjects photographed from high altitudes and therefore the sensing and computing elements of the system were designed to conform with the data of Table II.

It should be noted at this point that the range designation of Table II is different from that of Table I. Although Table II is based upon the iris settings available as listed in Table I, Ranges 1, 2, and 3 of the automatic exposure control would only correspond to Ranges A, B and C of the diaphragm range selector if the system were limited to one shutter and film speed. Since this is not the case in practice, the ranges of Table II indicate the average subject brightnesses between which the automatic exposure control will cause the iris mechanism to drive the iris to its appropriate Bright, Hazy or Dull position, irrespective of the setting of the diaphragm range selector control.

The sensor is quite small and mounts directly on the camera body (see Fig. 4). The light-sensing element is a cadmium selenide photoconductive cell which has excellent thermal stability. A limiting aperture in the sensor housing provides the desired field of view. An appropriate neutral density filter is incorporated into the sensor to reduce the light intensity to the optimum response range of the cell. This arrangement also insures that the cell's power dissipation limit will not be exceeded when the sun is included in the field of view of the sensor.

The response of the photoconductive cell may be expressed by the following approximate relation:

$$R = kL^{-\gamma}$$

Where R is the cell resistance,

L is the effective subject brightness in foot-Lamberts, and
k and γ are constants related to the geometry and physical characteristics of the cell.

For a series of typical sensors, γ was approximately 0.6 over more than two decades of L values. A plot of the logarithm of sensor resistance against the logarithm of subject brightness is presented in Fig. 6.

The photoconductive cell is part of a bridge circuit that incorporates transistor switching circuits as level-detecting elements, biased to produce the switching sequence of Fig. 7. This function is centered about the average brightness level of 2,000 foot-Lamberts. For example, with the diaphragm range selector switch set to Range B and the computer range switch set to Position 2, the iris setting would be driven to Hazy or *f*/9.5 for a brightness value of 2,000 foot-

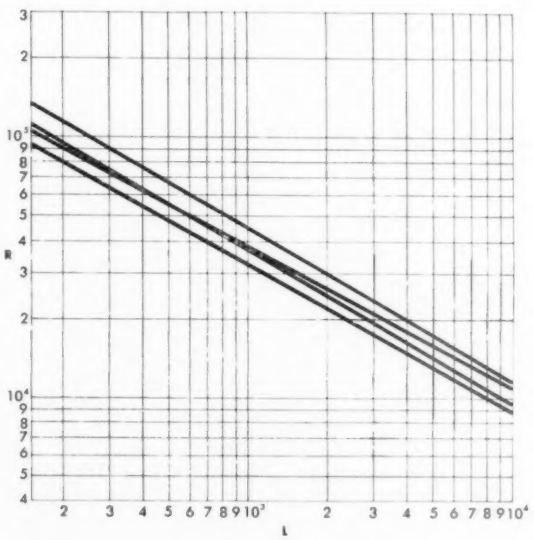

Fig. 6. Logarithm of sensor resistance in ohms (R) vs logarithm of subject average brightness in foot-Lamberts (L).

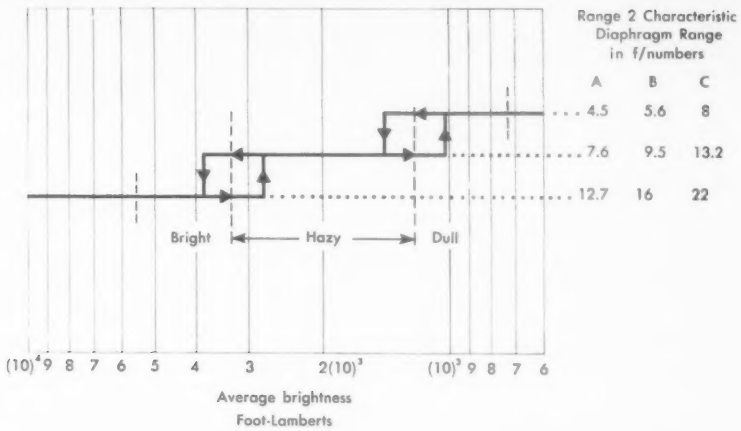

Fig. 7. Diagram of switching sequence.

Lamberts. This would yield optimum exposure for a shutter speed of 1/1000 second and a film speed equivalent to ASA 100. At *f*/16, the best exposure would be obtained for an average subject brightness of 5,660 foot-Lamberts. Since this change in aperture equals 1.5 *f*/stops, the transition region between Bright and Hazy, where switching occurs, centers about a brightness of 3,260 foot-Lamberts, or 0.75 *f*/stops, between the two aperture settings. A guard band, or hysteresis region, equal to 0.25 *f*/stop is introduced on either side of the switching point to prevent excessive switching that might be caused by slight changes in subject brightness.

Three different values of resistance in the photocell, or input, side of the bridge provide the three different ranges for the computer, described previously. A

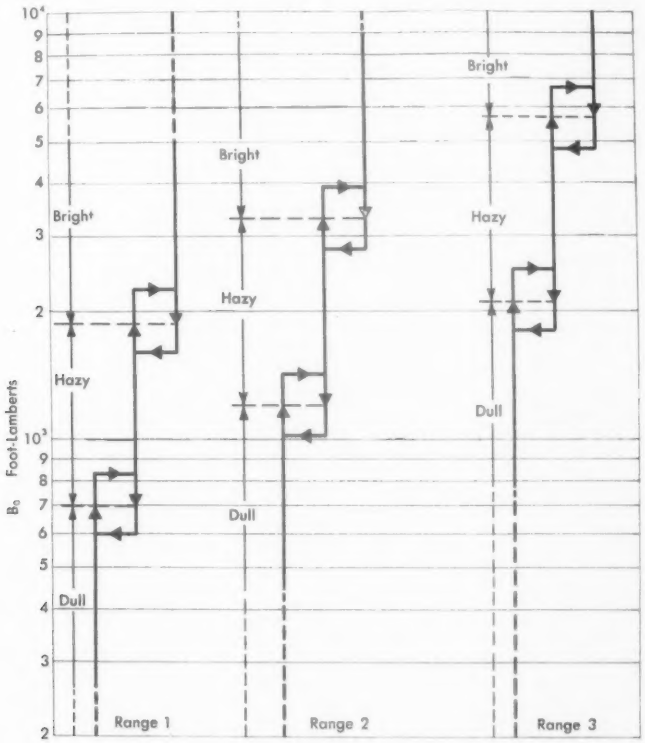

Fig. 8. Diagram of the switching arrangement.

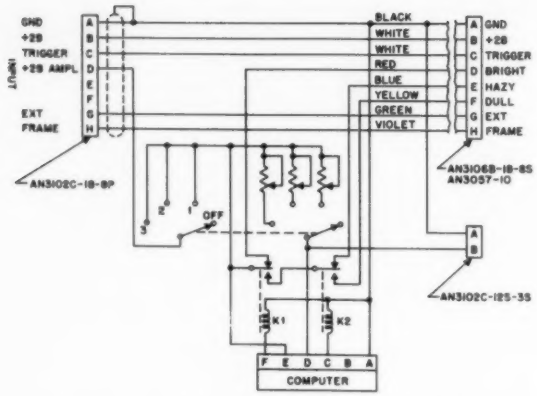

Fig. 9. Schematic diagram of the sensor-computer system.

diagram of the switching arrangement is reproduced in Fig. 8. The computer range selector is set before a mission in conformance with the speed of the film and filter to be used.

These values are correlated with film speed and shutter speed in Table III.

When a filter is used with a factor of 2, the exposure time is doubled or the diaphragm range selector is set to the next lower value, e.g., to A from B.

The computer range selector is preset to 1, 2, or 3, depending on the estimate of probable scene brightness. The final preflight adjustment is made in ac-

TABLE III

Film ASA	Shutter Speed	Diaphragm Range Selector	Computer Range Selector
25	1/500	A	2
		B	3
	1/1000		
	1/2000		
50	1/500	A	1
		B	2
		C	3
	1/1000	A	2
		B	3
	1/2000		
100	1/500	B	1
		C	2
	1/1000	A	1
		B	2
		C	3
	1/2000	A	2
		B	3
200	1/500		
	1/1000	B	1
		C	2
	1/2000	A	1
		B	2
		C	3

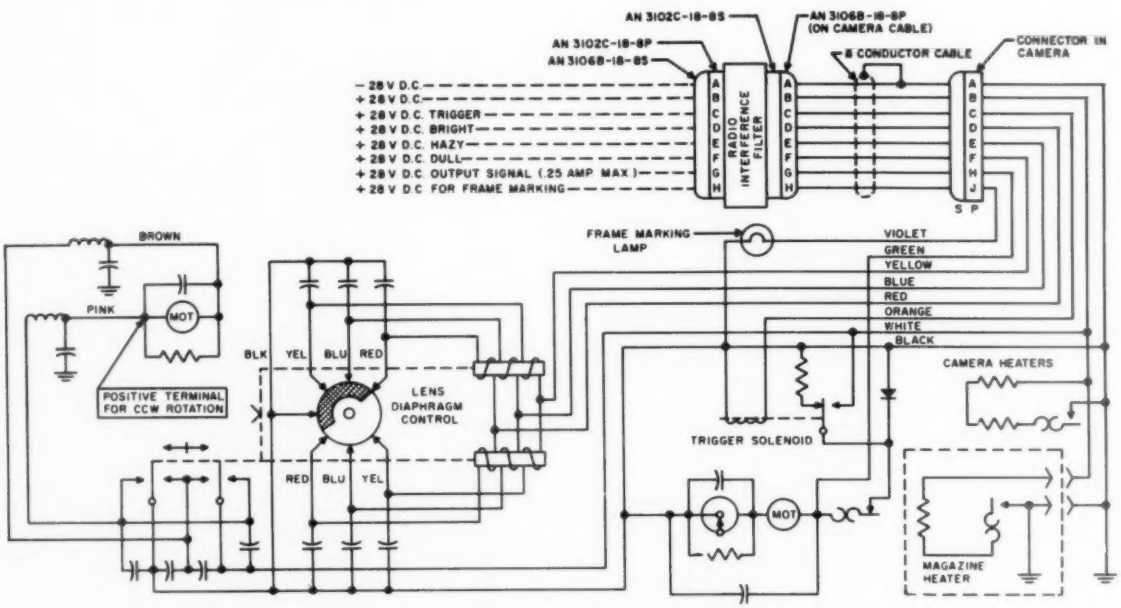

Fig. 10. Schematic diagram of the P-220 camera system.

cordance with Table III, after the film speed and desired shutter speed have been established.

A schematic diagram of the sensor-computer system is shown in Fig. 9. The block designated "computer" is a printed circuit assembly which includes five transistors. This unit is encapsulated and mounted as a subassembly in the computer case. The output circuit operates two subminiature relays whose contacts are arranged to switch the 28-volt d-c power supply to the Bright, Hazy, or Dull circuits in the camera. This action energizes the proper diaphragm solenoid coils through the positioning commutator to cause the iris motor to rotate in the proper sense. The motion of this motor brings the lens iris to the predetermined stop and, at the same time, rotates the follower portion of the commutator to de-energize the motor when this portion is reached.

Although this system was designed for the P-220 camera, it may be used in conjunction with the J. A. Maurer, Inc., current-production P-2 camera without modification of the camera or the automatic control circuitry, as long as adequate radio noise filtering is available. The basic system may be used also with most other cameras when an appropriate iris indexing and driving means is provided.

The exposure control system may be used at lower light levels than those indicated in Table II by changing the neutral density filter in the sensor. The system could then provide optimum exposure control, starting from an average brightness of approximately 8 foot-Lamberts. In addition, the range adjusting potentiometers may be used to extend the range of control by about 1.5 *f*/stops.

Optical Performance

Optical tests made with a number of representative production cameras (lens-camera-magazine combinations) on Kodak Super-XX Aerographic Film, processed in Kodak Developer D-19 to a gamma of 1.30 ±0.15, yielded the high-contrast resolution data shown in Table IV. (The exposures were made at a pulse rate of 1 frame every 6 seconds.)

The Area Weighted Average Resolution (AWAR) is 48.9 lines/mm for these test conditions.

Additional Specifications

A schematic diagram of the entire camera is given in Fig. 10.

TABLE IV

Average Radial and Tangential Resolution With Lens Aperture Wide Open (*f*/4.5)

Location	Lines/mm
On axis	61.5
10 degrees	60.4
20 degrees	55.7
30 degrees	52.0
40 degrees	36.6
45 degrees	23.4

Film — The Model P-220 camera takes $2^1/_4 \times 2^1/_4$-inch pictures on 70mm film perforated according to MIL-STD-33525. The film advance per frame is 14 perforations, or 2.618 inches.

Mounting — The camera has three $^1/_4$-20 threaded sockets on two sides of its body to permit secure mounting in the aircraft.

Power Requirements — The P-220 camera system operates from a d-c power source of 24 to 29 volts. The input current is 4.3 amperes when the main drive motor as well as the camera and magazine heaters are on. The power consumption of the automatic exposure control unit is only 3 watts.

Size — The P-220 camera with standard 50-foot magazine is $10^3/_8$ inches long, $5^3/_{16}$ inches wide and $4^1/_{16}$ inches high. The overall length is reduced to $7^3/_{16}$ inches when a 15-foot magazine is used. The computer measures $3^3/_8 \times 5 \times 2^3/_4$ inches.

Weight — The entire P-220 camera system, including 50 feet of film in the magazine, weighs 9 pounds 10 ounces. The sensor contributes 5 ounces and the computer 1 pound to this total.

Environmental Conditions—The P-220 camera system can be operated in the temperature range of −65 to +160 F, it functions under conditions of severe vibration, and it operates while undergoing accelerations up to 8 G's in any direction. It conforms to the requirements of radio noise tests specified in MIL-I-6181.

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Volume 1, Number 4, March 1958

Methods of Dimming Hot-Cathode Fluorescent Lamps

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Eastman Kodak Company, Rochester, N.Y.

Two types of dimmers for fluorescent lamps are described, neither of which increases or introduces ripple into the light output. The first type depends on a resistance that is varied mechanically. It covers a range of light output of 1000:1 and is suitable for either direct or alternating current. On the other hand, it is limited in speed of variation, requires an excessively wide range of control resistance, and is far from linear with respect to this resistance. The other is an electronic arrangement which, although having a practical range of only about 200:1 and being suitable only for direct current, is simple, and is limited in speed of variation only by the rise and decay characteristics of the phosphors in the lamp. It is suitable also for automatic instrumentation because it is controlled by the bias of a vacuum tube and is practically linear with this bias.

The fluorescent lamp is especially suitable for photographic printing because of its size, shape, low operating temperature, long life, and the variety of spectral emissions available. In such applications, however, it is often convenient to control exposure by controlling the luminance of the light source, and with fluorescent lamps this requires special equipment.

Several techniques for dimming hot-cathode fluorescent lamps by electrical means have been developed for use on 60-cycle alternating current,[1,2,3] and some have been adapted to commercial equipment. In general, these techniques depend on varying the time interval of conduction during each half-cycle of the current variation. This procedure has the disadvantages that the maximum range of luminance control is only about 200:1 and the ripple content of the light output becomes extremely high. In addition, the speed of control is limited by the speed with which a control shaft can be positioned but, even when this limitation is overcome by electronic means, the frequency of the power source still sets an upper limit.

Lamp Characteristics

To achieve satisfactory control of the light output from fluorescent lamps over any appreciable range, whether the source is a-c or d-c, the following basic requirements must be met[1,2,4]: (1) The cathodes must be maintained at a temperature high enough to produce a copious supply of electrons, regardless of lamp current. (2) Since the fluorescent lamp is a gaseous discharge device and inherently possesses a negative resistance characteristic, sufficient series impedance to ensure stability must be provided. (3) The voltage across the electrodes must be sufficiently high to maintain the discharge at any required level of brightness. (4) Adequate current for easy starting must be provided.

As can be seen from Fig. 1, the light output of a fluorescent lamp decreases little during all but the first few hours of operation, when it decreases extremely rapidly. During this initial period, lamps also exhibit erratic starting behavior when used with a dimmer that is set for a low light output. For these reasons, all lamps should be aged through normal operation for about ten hours before they are used with a dimmer. All data presented in this paper were obtained with seasoned lamps.

A Wide-Range A-C or D-C Resistance Control

The circuit in Fig. 2 meets the requirements just listed and can also be used to measure the steady-state characteristics of one or more lamps in series. Each cathode is supplied from an individual 6.3-volt transformer. If the lamp is operated on direct current,

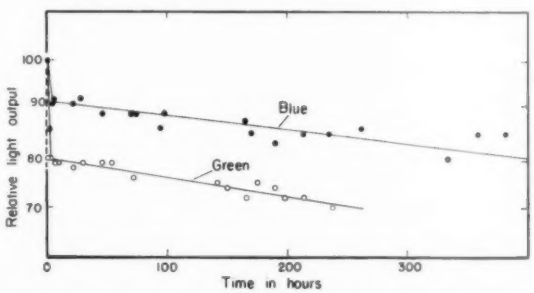

Fig. 1. Depreciation of light output with time for typical 15-watt T-8 lamps. Data for standard blue and green phosphors are shown.

Communication No. 1929 from the Kodak Research Laboratories, presented at the Annual Conference, Asbury Park, N.J., 13 September 1957. Received 14 October 1957.

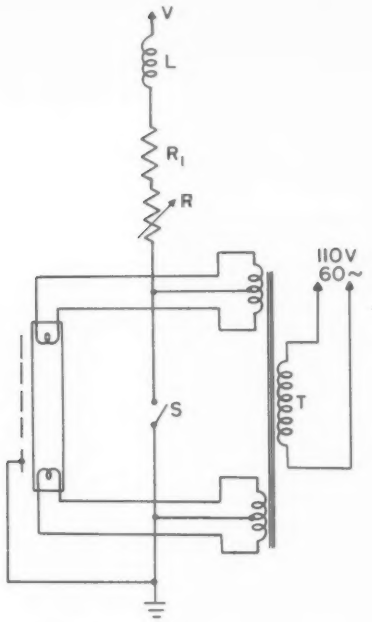

Fig. 2. Circuit for controlling light output of a fluorescent lamp by means of an adjustable series resistance.

only one cathode need be heated since the electron flow is unidirectional. The luminance of the lamp is controlled by resistor R with the minimum resistance fixed by resistor R_1.

When the switch S is opened, the inductance L provides a transient that starts the lamp. For reliable starting, a grounded conductor in close proximity to the lamp is recommended.[1,2,3,5] It has been suggested that the initial breakdown of the gas is aided by capacitive current from the ends of the lamp to ground that extends ionization throughout the length of the lamp. The condition of the lamp surface obviously affects this process, and the method of starting described in the next section is considerably better.

The relation between the light output of a 15-watt T-8 lamp and lamp current, plotted on logarithmic coordinates, is shown by Curve A in Fig. 3. Curve B shows the voltage drop across the lamp, plotted on a linear scale, also as a function of lamp current. These curves are typical of a wide assortment of lamps of various wattage ratings and manufacture.

Evidently the light output of the lamp is almost linear with current over a range of light output exceeding 1000:1. The departure from linearity at high currents probably arises from the increased gas pressure brought about by increased temperature. The normal operating point of this lamp lies at about 300 milliamperes (ma). At low currents, the operating conditions become critical and some care is required to prevent the lamp from extinguishing. This instability is probably caused by a rapid rise in lamp voltage as the current drops below 0.5 ma.

Curve B indicates why the luminance of the lamp cannot be controlled by varying the voltage. The

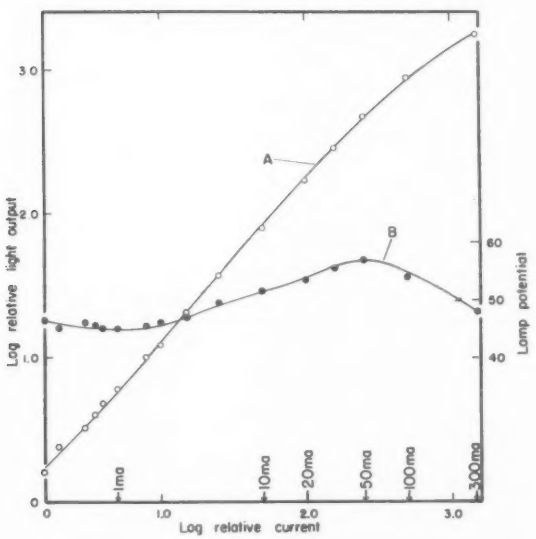

Fig. 3. Series resistance control of a typical 15-w., T-8 lamp operated on direct current: Curve A — relative light output; Curve B — potential across lamp as functions of relative current.

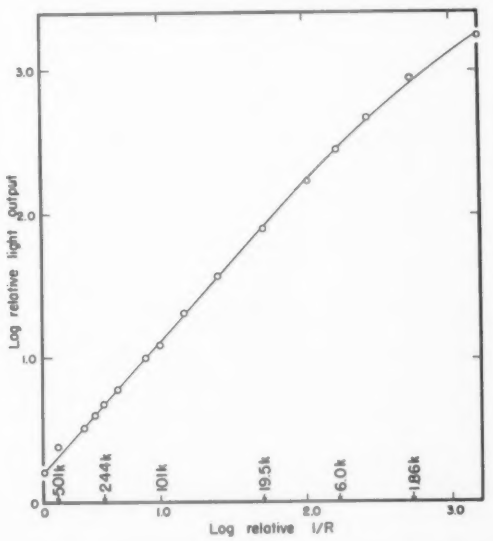

Fig. 4. Series resistance control of a typical 15-watt, T-8 lamp operated on direct current. Relative light output vs reciprocal of series resistance.

slope $\Delta V/\Delta I$, which represents the resistance of the lamp, has a negative value for lamp currents above 50 ma, and probably also for currents below 1 ma, as just mentioned. A simplified explanation of this phenomenon has been given elsewhere.[6] The practical result is that the lamp acts like a negative resistance and thus requires a series ballast.

The characteristics of a suitable arrangement in terms of the control resistor are shown in Fig. 4. It will be noted that the light output is inversely proportional to the control resistance, and for this reason linear control is difficult to achieve. Such a result is to be expected since the current is limited chiefly by the control resistor and, for a fixed potential difference, current is inversely proportional to resistance. Moreover, the range of resistance is excessive. For example, 500 ohms give a current of 300 ma, whereas 1.5 megohms are required to reduce the current to 0.2 ma.

This type of control also has the disadvantage that it is not suitable for lamps operated in parallel because their voltage-current characteristics are not identical. Even when an equalizing resistor is introduced in series with each lamp, the first lamp to start will carry most of the current and the remaining lamps either will not start at all or will not respond consistently. A better solution is to place the lamps in series and to use a higher over-all potential.

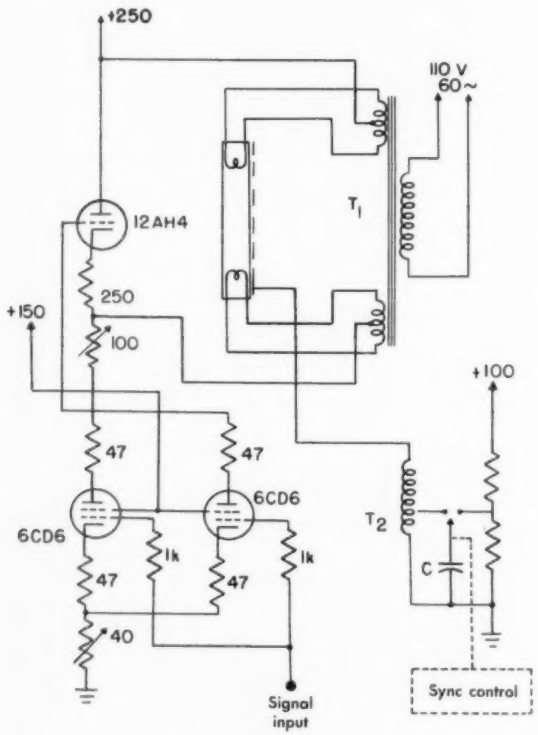

Fig. 5. Vacuum-tube circuit for rapid control of light output of a fluorescent lamp.

A Rapid D-C Electronic Control

A system that is free from most of these disadvantages, although at a sacrifice in range, is depicted in Fig. 5. The values given are for a single 15-watt T-8 or 14-watt T-12 lamp, but they can be varied for other lamp combinations. This circuit differs from that shown in Fig. 2 in three respects: (1) The series control resistor is replaced by a pair of power pentodes. (2) A low-mu triode is connected across the lamp. (3) An external high-voltage probe is used as an aid in starting.

Power pentodes will regulate the current much faster than a mechanical control device will, but, owing to the remote cutoff characteristics of such tubes, the light output is not at all a linear function of control grid voltage, as is evident from Curve A in Fig. 6. This lack of linearity is compensated for by the use of a Type 12AH4 triode connected across the lamp. At high lamp currents (above about 200 ma for the 15-watt T-8 lamp), the cathode of the 12AH4 is held at a positive potential by the high current through the cathode resistor. The resulting grid bias cuts off the 12AH4, and renders it ineffective. As the plate current of the 6CD6 tube is diminished, this bias decreases and a portion of the 6CD6 plate current begins to flow through the 12AH4 until, at low plate currents, most of the current that would otherwise pass through the lamp is bypassed by the 12AH4. This results in the sharp cutoff of Curve B in Fig. 6. The slope of Curve B in the low light-output region

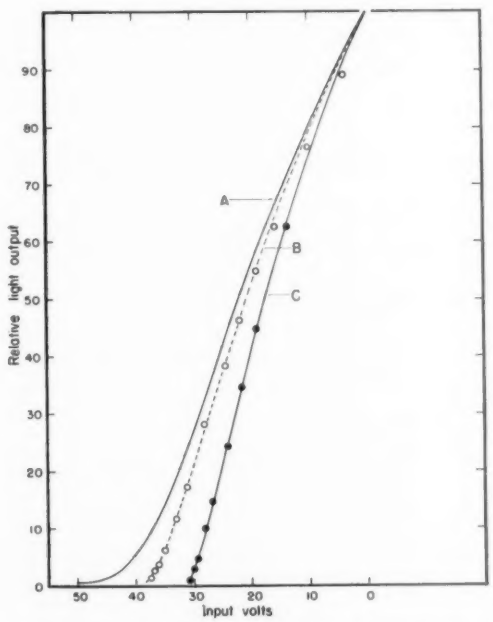

Fig. 6. Relative light output of a typical 15-watt T-8 lamp vs amplitude of control signal. Curve A — 6CD6 control tubes only; Curve B — 12AH4 in shunt with lamp; Curve C — 6AQ5 in shunt with lamp.

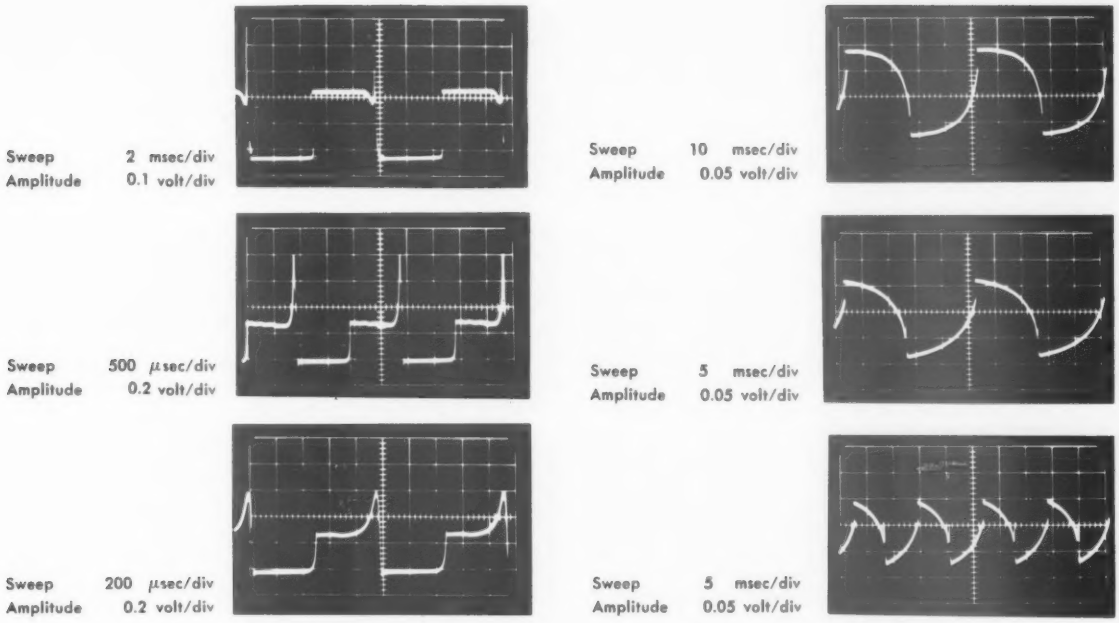

Fig. 7. Modulation of typical 15-watt T-8 lamps. Left, blue phosphors; right, green phosphors.

can be controlled somewhat by adjusting the cathode resistance.

Somewhat better linearity over the entire range of input signal can be obtained if a pentode is substituted for the triode, but then a floating screen-grid supply is required. Curve C indicates the improvement obtained by substituting a beam pentode (6AQ5) for the 12AH4 triode.

A disadvantage of the parallel control tube system is the fact that the range over which lamp currents can be reliably controlled is decreased. At currents below 1 to 2 ma, switching transients or spurious signals of a volt or less can occur in the control signal and extinguish the lamp. The range of controlled light output is thus limited to about 200:1.

In the circuit as discussed so far, the lamp will be self-starting under the following conditions: The supply voltage must be sufficiently high (about 300 to 400 volts), the light intensity desired immediately after starting must be reasonably high, and the control signal must have a short rise time. If these conditions are met simultaneously, the voltage appearing across the lamp at the start of the control signal will exceed the striking potential and the arc will be initiated. However, these conditions are not always fulfilled. For example, it is desirable to be able to start the lamp at a low intensity. To ensure immediate and reliable starting, the auxiliary circuit shown in the lower right-hand corner of Fig. 5 was incorporated. A high-voltage transient is generated when the capacitor C is discharged through the autotransformer T_2 and is applied to a probe placed close to the lamp. This action may be initiated manually by closing the indicated switch or automatically by means of an external, synchronized timing device. As mentioned previously, this system can also be used with the dimmer described in the preceding section.

A foil strip cemented to the glass envelope of the lamp makes a convenient probe, but neither its shape nor location appear to affect its effectiveness. For example, a wire loop located anywhere within a few inches of the lamp appears to work equally well. When more than one lamp is to be controlled, the probe should be equidistant from each lamp to ensure that all start at the same instant. This is especially important when several lamps are connected in series.

The time required to bring the light output to the desired value is determined principally by the response time of the phosphor in the lamps. Figure 7 shows the light output as a function of time for two 15-watt T-8 lamps, blue and green, when a square-wave modulating voltage is applied to the grids of the control tube. The signal was recorded from an oscilloscope associated with a photoemissive tube. Owing to image inversion in the camera, the time base follows from right to left on these diagrams.

In this experiment, the control signal was repetitive and the current was brought to its rated value each half cycle. Thus, the conditions approximated those in normal usage, and the lamp could be operated without the starting circuit once the arc had been struck.

The light output of the blue lamp under these conditions follows the square-wave input signal with reasonable fidelity up to a frequency of about 2000 cycles per sec. Daylight lamps also show about the

same response. The output of the green lamp, on the other hand, clearly shows the rise time of the fluorescent and the decay time of the phosphorescent radiation. Its use is thus limited to correspondingly lower modulation rates.

It will be observed in Fig. 7 that a pulse approximately 100 μsec wide appears at the leading edge of each wave, i.e., each time the lamp is turned on. It is believed that this is caused by radiation from the excited mercury vapor, the 2537A line being particularly intense in fluorescent lamps.

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ERRATUM

John Eggert, "The Present Status of Photographic Development in Theory and Practice," *Phot. Sci. and Eng.*, Vol. 1, No. 3, p. 103.

Lines 5–7 in item 32 of the Bibliography should read: "...a remarkable study on color coupling by Eggers, J., and Frieser, H., *Z. Elektrochem.*, Vol. 60, p. 372 (1956)."

• Technicalia Photographica

FRANK SMITH

• Cameras, Components, and Accessories

Spectra Brightness Spot Meter

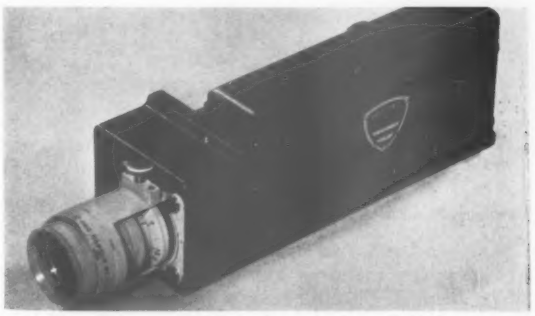
A new brightness spot meter, the Spectra Model C-3, said to be a greatly improved version of previous models, has been developed by the Photo Research Corp., 837 N. Cahuenga Blvd., Hollywood 38, Calif. The meter is self-contained and portable.

The meter incorporates an $f/1.9$ lens that focuses an image of the region being measured onto a reticle plane. By looking into the viewing eyepiece, an area several times that being measured is seen surrounding a black dot. The area covered by the black dot, approximately a three-degree angle of view, is the area whose average brightness is being directly indicated by the foot-Lambert reading on a microammeter. The range of the meter can be extended by the factors of 1, 10, 100, and 1,000, by turning a control on the side of the instrument. The spectral response closely matches the C.I.E. luminosity curve.

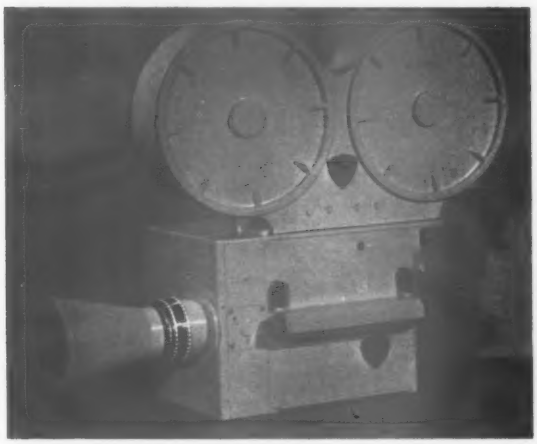
The minimum measurable brightness is 0.5 foot-Lambert, the maximum without supplementary filter is 50,000 foot-Lamberts; the claimed accuracy is 5 per cent of reading. The size of the Spectra Model C-3 is $8^1/_2 \times 8^1/_2 \times 3$ inches and its weight is $3^3/_4$ pounds.

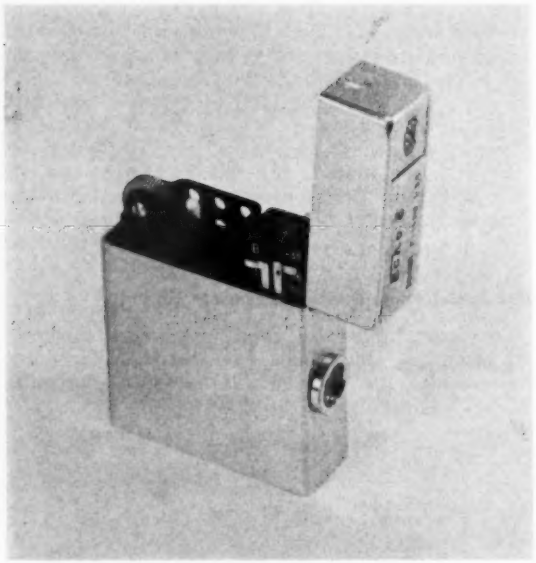
High-Speed Photographic Instrumentation

Two new high-speed rotary-prism-type cameras, one 16mm and one 35mm, have been developed by Photo-Sonics, Inc., 2704 West Olive Ave., Burbank, Calif.



The Model 1B is a full-frame 16mm camera with interchangeable film magazines; it is capable of resolving 65 lines per mm. The 35mm version, Model 4B, also is a full-frame camera that resolves 65 lines per mm on the axis and is capable of operating at speeds of up to 2800 frames per second. It has interchangeable shutters with 5 to 60 degree openings and a 500-foot film capacity. Model 4B is equipped with fiducial markers, a two-light timer, 10× viewing tube, buckle and runout shut-off switches, and optional frame rates below 2800. Lenses are available in 80, 135, 250 and 550mm focal length.





The "Echo 8" is described as a precision-made, high-quality camera contained within a regular, working, windproof Zippo cigarette lighter. It is equipped with a coated, 2-element, fixed focus, *f*/3.5 Echor lens, optical reflex viewfinder, all-steel body, screw-in type filter mount, $^1/_{60}$-second and bulb shutter speeds, and automatic film advance stop. It uses 8mm film in special daylight-loading magazines with 20 exposures, 6 × 6mm format. The size of the camera is $1^3/_4 \times 2^1/_4 \times {}^3/_4$ inches, its weight $5^3/_4$ ounces.

Radio-Controlled Camera Unit

A radio control unit which permits remote control of the Praktina FX Camera without external wiring at distances of more than a mile has been announced by Standard Camera Corp., 319 Fifth Ave., New York, N.Y. The unit works in conjunction with the Praktina FX Camera and the Praktina FX Electric Motor. Up to 420 consecutive exposures can be made with the aid of a Praktina FX 50-foot-capacity bulk film magazine, or 20 or 36 exposures with standard 35mm cassettes.

In operation, the receiver component of the radio control unit is plugged into the Praktina FX Camera. The transmitter component may then be used at any distance up to about one mile from the camera to close a relay circuit that activates the electric motor which in turn operates the camera. Specifically, the shutter is released, then the film transported to the next frame, and the shutter is rewound for the next exposure.

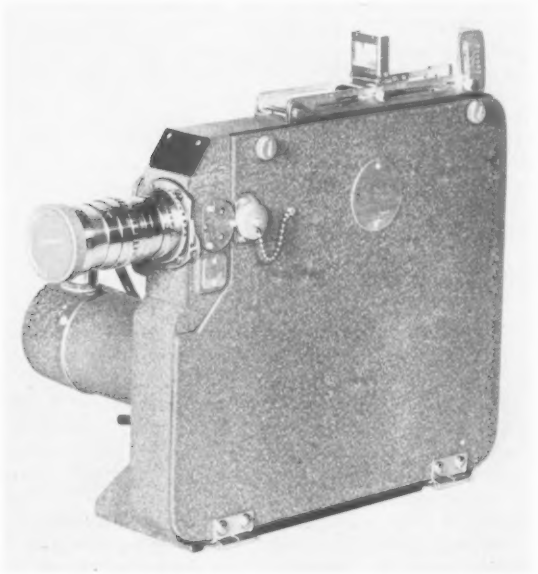
New Sub-Miniature Still Picture Cameras

New and unusual subminiature still cameras are the "Echo 8" cigarette lighter and the "Stylophot" fountain-pen-type cameras distributed by Silver Bells, Ltd., 1637 Del Monte Blvd., Seaside, Calif.

The "Stylophot" is a subminiature fountain-pen type camera manufactured in France. It accepts standard 16mm or double 8mm black-and-white or color film in 18-exposure daylight-loading magazines. An eye-level optical viewfinder provides a 10 × 10mm image. The shutter speed is set at $^1/_{50}$ second and shutter winding and film advance are combined and automatic, and are supplemented by double-exposure prevention and an automatic exposure counter. The camera is $4^1/_2$ inches long and weighs approximately 3 ounces. There are two models, the Standard and the Deluxe. The Standard is equipped with a double-element coated 27mm *f*/3.5 lens and built-in standard or electronic flash synchronization.

Lightweight High-Speed Motion Analysis Camera

A high-speed 16mm camera of light weight has been introduced by Fairchild Camera and Instrument



Corp., Industrial Camera Div., 88-06 Van Wyck Expressway, Jamaica 1, N.Y. Interchangeable motors provide picture-taking rates of 10–80, 25–300, 200–1500, 500–2500, and 800–6000 frames per second.

The camera, Model HS-401, is said to produce smear- and vibration-free images at all speeds and is equipped with an open sight that incorporates focal length and parallax correction. It is delivered with a 13, 75, 102, or 152mm lens. A boresight slips easily into the port of the camera.

The camera with a 75mm lens measures $9 \times 13^{1}/_{4} \times 16^{13}/_{16}$ inches. Motors, lenses, and auxiliary equipment are interchangeable with the HS-100 and HS-101 models. A full line of associated equipment has been designed for use with these Fairchild Motion Analysis Cameras.

Oscilloscope-Record Cameras

Two new oscilloscope-record cameras, Types 299 and 302, have been made available by Allen B. DuMont Laboratories, Inc., 760 Bloomfield Ave., Clifton, N.J., for single-frame photographs of 5-inch oscilloscope displays.

Type 299 may be obtained with various backs that accept different sizes of conventional film. Type 302 is equipped with a Polaroid-Land back and is used where there is a need for minimum delay between recording and viewing. Both cameras are offered with a simple, inexpensive conversion with which one

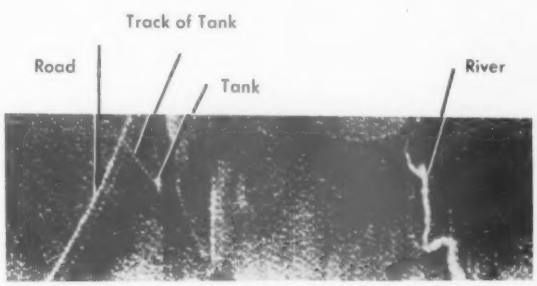
type can be changed into the other. The normal Type 299 camera uses standard No. 120 roll film, while Type 302 uses Polaroid Type 41, 44, 46 or 46L 8-exposure rolls. The image reduction ratio is 2.25:1. A full line of accessories is available.

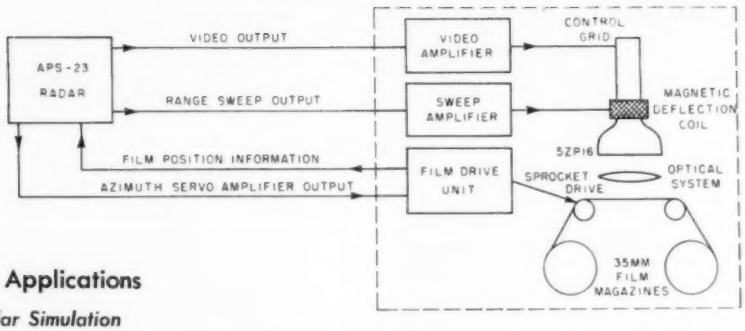
Infrared Photo Reconnaissance System

Several photographs recently declassified by the U.S. Air Force, and released by the Servo Corp. of America, New Hyde Park, N.Y., show the effectiveness of infrared reconnaissance as a military weapon. The photographs were taken with a system designed and manufactured earlier by the Corporation. These "thermal mappings" of military ground installations, airfields, and civilian sites demonstrate the astounding ability of infrared recording techniques to translate into a photographic image the heat patterns of ground targets, even when they are camouflaged.

In a photograph of this type, made at night from an altitude of 3,000 feet, a road, a tank and its track marks, trees, and a meandering river, all in a heavily wooded area, are clearly revealed.

It is claimed that the system has the ability to remain coordinate and that it cannot be jammed by electronic counter-measures. It is effective day and night, and does not reveal its position.





• Techniques and Applications

Video Recorder for Radar Simulation

The Stanford Research Institute, Menlo Park, Calif., has announced development of a unique radar simulation system which combines both radar and photography to produce a device for instructing student navigators on the ground in the use of airborne radar. The equipment is described by Ralph M. Heintz of the Television Laboratory at SRI in *Electronics*, Vol. 30, pp. 146–149 (Sept. 1, 1957).

The system developed by SRI involves the conversion of electrical signals to light and storage of the variation in intensity on film. There are two units, an airborne video recorder and a ground-based playback. The airborne unit, designed around a conventional ppi radar indicator, records the video output of the operating radar directly on 35mm film. An intensity-modulated cathode-ray tube with stationary sweep is continuously photographed by the moving film, whose motion is synchronized with the rotation of the radar antenna. Ground-based playback consoles, with range and azimuth-mark generators, permit trainees to measure or interpret the target situation.

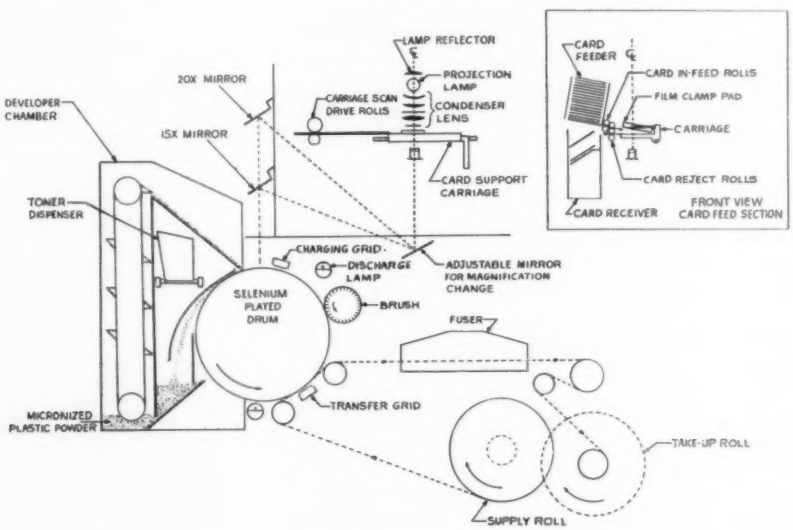
In addition to its military application, the equipment is expected to be useful in training commercial airline radar observers.

Enlarged Engineering Drawings from Microfilm by Xerography

The Navy Bureau of Aeronautics has disclosed that it is using an ingenious, low-cost method of producing enlarged engineering drawings from microfilm.

The printing is done from microfilm in a Xerox Copyflo 24-inch continuous printer, manufactured by the Haloid Co., Rochester, N.Y. The printer produces drawings up to two feet wide completely automatically at a speed of 20 feet per minute. Individual microfilm frames are mounted in die-cut apertures of cards punch-coded for various sorting purposes, and emerge from the printer in the order of entry. A push button that repeats the exposure makes possible the production of up to 400 prints from a single frame. With an auxiliary attachment, roll microfilm in either 16mm or 35mm size may also be used. Reduction rates in the Copyflo printer are 16× or 29×. Enlargements are either 15× or 20×.

The Navy proposes to use the Copyflo printer and other related equipment to furnish its potential suppliers with necessary drawings and specification sheets together with invitations for bids.



Electrophotography Applied to Oscillography

Calvin O. Vogt and John C. Westervelt, *Indus. Phot.*, Vol. 6, pp. 52–54 (June 1957).

A brief description and discussion covering the Electrograph, a new recorder utilizing the principles of electrophotography. The process depends on a photoconductive sheet which is electrically charged, exposed to produce a latent image, and then dusted with finely charged particles to make the image visible. The sheet, known as Electrofax, is similar to conventional silver halide oscillographic recording paper except for the coating which consists of an emulsion of finely-divided, photoconductive materials (such as special zinc oxide) in an insulating binder (such as silicone resin). The paper has a speed of approximately $^1/_{30}$th that of Kodak Linagraph 809 recording paper.

The Electrofax recording paper comes in 200-foot rolls and is 8 inches wide. The zinc oxide coating has a spectral response in the ultraviolet region only but this may be extended by dye sensitization. Illustrated.

Technical Photography, Documentary

S. A. Anthony and Robert Crook, *Operation Teapot* (U.S. Atomic Energy Commission), W.T.-1169, 34 pp. (June 1956).

A discussion of the use of documentary photography in evaluating the physical damage from atomic test operations. [*Battelle Tech. Rev.*, Vol. 6, No. 9 (Sept. 1957), Abstract No. 13265.]

The Operation of a Miniature Camera by Remote Control

D. E. Blackwell and D. W. Dewhirst, *J. Sci. Instruments*, Vol. 34, pp. 274–276 (July 1957).

The difficulties encountered in devising a mechanism for automatically winding and releasing the shutter of a Contax camera are discussed and a suitable clutch mechanism is described. Illustrated.

● Miscellaneous

The Accuracy of Photographic Intensity Measurements of Absorption Spectra

Alf Lofthus, *Spectrochimica Acta*, Vol. 9, pp. 216–226 (1957).

Some of the experimental methods used in photographic absorption spectroscopy are discussed, with special emphasis on the sources of error associated with them. On the basis of these discussions, the experimental conditions leading to the smallest total error of intensity measurements can be found.

The application of the results to chemical analysis is discussed. A comparison is made between the photographic and the photoelectric methods. 12 references.

Interpolation Formulae in Photographic Spectrophotometry

E. A. Baker, *J. Phot. Sci.*, Vol. 5, pp. 94–95 (July-Aug. 1957).

The nomenclature of a recent paper by C. Candler on this subject differs from that of the revised *Theory of the Photographic Process*, by C. E. K. Mees, and neither adopts long-established usage in stellar spectrophotometry. The best-known formulas are here shown to be special cases of a more generally applicable formula deduced from plausible assumptions, and a compromise notation is suggested. Illustrated. 8 references.

Agfa, Inc., Opens New York Office

After an absence of nearly 20 years, Agfa Incorporated has returned to the United States at 515 Madison Ave., New York 22, N.Y., with a full line of cameras, chemicals, papers, and black-and-white and color films. Old timers in the photographic field may recall that Agfa put its first color plate on the market in 1916.

The Agfa cameras include the Automatic 66, a $2^1/_4$-$\times$ $2^1/_4$-inch camera using No. 120 roll film, and the Ambi Silette, a new rapid-action 35mm camera with three interchangeable lenses. Black-and-white films include Agfa Isopan F, 32 ASA, and Agfa Isopan Ultra. The company claims that Isopan Ultra is the only single-layer-emulsion high-speed film on the market.

The color films, Agfacolor CN 17 and Agfacolor CU 18, will not be on the market until spring, when proper processing facilities will be available. Agfacolor CN 17 is a new high-speed color-negative film with an exposure index of 32 and Agfacolor CU 18 a high-speed reversal film for color slides with exposure index of 40.

As Others See It

Lloyd E. Varden, *Indus. Phot.*, Vol. 6, pp. 40, 42, 44 and 70 (Sept. 1957).

The new Photocopy Duplicator of the A. B. Dick Co. is described. The Duplicator is a combined exposing and processing machine using the silver ion diffusion transfer process. The fundamental requirements of this process are the subject of U.S. Patent No. 2,352,014, granted June 20, 1944, to Andre Rott of Gevaert, Belgium.

A practical application of fiber optics, the Fiberscope, is also described. This snake-like tube 3 feet long and $^1/_2$ inch in diameter contains some 40,000 tiny glass fibers, each 3 feet long. At the base end of the device is a series of mirror reflectors to send the image back up the tube. A thin electric wire runs down the side of the instrument and carries power to a small floodlight which illuminates the cavity. The fiberscope can take color pictures inside a small, dark cavity. Those interested in obtaining further information are referred to Dr. G. W. Peters, University of Michigan, Ann Arbor, Mich.

• Patent Postscripts

ROBERT H. ZAPPERT

Combined Developer and Fixer

U.S. 2,782,120, Jerome S. Goldhammer and John A. Maurer

Monobaths that exhibit high activity at pH values of 9.5 or less contain amidol, or amidol-type substances, as principal developing agent to initiate rapid development of the latent image, and a dihydroxybenzene, in the range from 7.5 to 200 per cent by weight of the principal developing agent, to inhibit the usual fast deterioration of amidol in alkaline solution. A third developing agent, a preservative, an alkali, a fixing agent and an anti-foggant are included in most of the formulas that are disclosed. A typical formula is:

Water	1 l
Sodium sulfite (anhydrous)	50 g
Amidol	15 g
Glycin	10 g
Hydroquinone	5 g
6-nitrobenzimidazole nitrate	0.4 g
Sodium carbonate (monohydrate)	50 g
Sodium thiosulfate (crystal)	100 g

The new monobaths are claimed to overcome the disadvantages of former formulas that either caused excessive swelling of the emulsion gelatin and consequent physical damage owing to high solution pH (about 11.0), or required long processing times (about 20 minutes) owing to low pH and limited hypo concentration.

Combined Developer and Fixer

U.S. 2,782,121, Jerome S. Goldhammer

The use of an alkali metal hydroxide, such as sodium hydroxide, together with ammonium thiosulfate is claimed to yield still higher activity, better solution stability, lower granularity, and enhanced sharpness than the monobaths disclosed in U. S. 2,782,120. A typical formula for high and medium speed panchromatic and orthochromatic films is:

Water (120 F)	750 cc
Sodium sulfite (anhydrous)	50 g
Amidol	15 g
Hydroquinone	5 g
Glycin	10 g
6-nitrobenzimidazole (0.5% solution)	80 cc
Potassium bromide	5 g
Sodium hydroxide	20 g
Ammonium thiosulfate	50 g
Water to make	1 l

Xerographic Plates for Radiography

U.S. 2,804,396, Osmar A. Ulrich, Jr., assignor to The Battelle Development Corp.

Xerographic plates that are insensitive to light but sensitive to x-rays and similar radiation are produced by depositing a selenium layer of from 5 to 75 microns thickness onto a conductive support, such as a brass plate, while the plate is maintained at a temperature of from 25 to 35 C. The selenium deposition is best carried out in a vacuum chamber at a pressure of 1 micron of mercury or less. A cardinal feature of the process is the control of the base plate temperature at 35 C or less, the optimum range being 25 to 30 C. The selenium deposited in this manner is indistinguishable from vitreous selenium formed under other conditions but its electrical properties and sensitivity are quite different, as described.

Yellow Colloidal Silver

U.S. 2,806,798, Clay Weaver, assignor to E. I. du Pont de Nemours and Co.

Yellow colloidal silver used in blue-absorbing filter layers for color film is prepared by reducing an aqueous dispersion of silver bromide in a water-permeable colloid such as gelatin or polyvinyl alcohol with an alkaline solution containing a reducing agent, such as hydrazine, *p*-phenylenediamine or *p*-methylaminophenol. The dispersion is coagulated and washed free of water-soluble salts.

Fixing Apparatus for Xerographic Card Printer

U.S. 2,807,703, David D. Roshon, assignor to International Business Machines

The xerographic toner image on a record card is fixed by heating the electroscopic toner with infrared radiation to the fusion point while cooling the card to keep it from warping. The electrostatic printer in which this scheme is employed was described in *Photographic Engineering*, Vol. p. 7, 137 (1956).

Thermographic Copy Sheet

U.S. 2,813,042, W. E. Gordon & S. E. Eaton, assignors to A. B. Dick Company

A copy is thermographically reproduced on a fibrous sheet sensitized with an aqueous solution of urea, thiourea, and a nickel or cobalt salt.

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